2

ASD-TR-92-5010

REQUIREMENTS FOR AN AUTOMATED HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING (HMPT) PLANNING TOOL

Susan M. Evans
Nicole A. Ritchie

Vector Research, Inc.
901 S. Highland Street
Arlington, VA 22204

MAY 1992

FINAL REPORT for PERIOD Aug 1991 - Jan 1992

Approved for public release; distribution unlimited.

DCS, Development Planning
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson AFB, OH 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Robert F. Bachert

ROBERT F. BACHERT
Project Manager
Development Planning Directorate

Nancy L. Clements

NANCY L. CLEMENTS
Chief, Requirements, Studies and Analysis
Development Planning Directorate

Frank Campanile

FRANK CAMPANILE
Chief, Requirements, Studies and Analysis
Development Planning Directorate

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify ASC/XRM, WPAFB, OH 45433-6503 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	MAY 1992	FINAL 08/01/91--01/31/92

4. TITLE AND SUBTITLE REQUIREMENTS FOR AN AUTOMATED HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING (HMPT) PLANNING TOOL

5. FUNDING NUMBERS
C F33657-91-C-2211
PE 65502F

6. AUTHOR(S) Susan M. Evans
Nicole A. Ritchie

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Vector Research, Inc.
901 S. Highland Street
Arlington, VA 22204

8. PERFORMING ORGANIZATION REPORT NUMBER
VRI-AFHEL-1 FR92-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ADVANCED SYSTEMS ANALYSIS
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AFB OH 45433-6503
ASD/XRM, Attn: BACHERT 513-2556261

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ASD-TR-92-5010

11. SUPPLEMENTARY NOTES
This is a Small Business Innovative Research Program, Phase I

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This Phase I Small Business Innovative Research (SBIR) project investigated the impact of system design decisions on human operator performance during concept development. The research established the functional and information requirements for an effective automated design analysis and crew performance assessment methodology for use in Premilestone I planning. The information structure included process, task, dynamic crew performance, operator graphic and human factors parameters, and training requirements. Existing automated tools such as the $IDEF_0$ structured analysis methodology, the SAINT task network simulation model, and various operator graphic and human factors models were evaluated, along with other proven methodologies such as IDEAL and the Air Force's Instructional Systems Development (ISD) process. Insights from designers and other potential users identified special functional, information, and hardware requirements which were included in the methodology.

The requirements will direct the implementation of an automated Human Factors, Manpower, Personnel, and Training System in Phase II. The resulting system will make a significant contribution to the complex problems of considering HMPT issues early in system planning. It has potential application by elements in DoD program offices and organizations, and would also be of use in the private sector by those who are involved with the early concept phases in the design of complex human-operated systems.

14. SUBJECT TERMS
Manpower, personnel and training, human performance, process modeling, IDEF, simulation modeling, concept exploration, system planning

15. NUMBER OF PAGES 87

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

PREFACE

The research presented here was performed under the Phase I Small Business Innovative Research (SBIR) contract number F33657-91-C-2211 titled "Requirements for an Automated Human Factors, Manpower, Personnel, and Training (HMPT) Planning Tool." The Air Force Aeronautical Systems Division (ASD/XRM) at Wright-Patterson Air Force Base (WPAFB), Ohio, was the primary sponsor, with additional support provided by the Human Systems Division (HSD) at Brooks AFB, Texas. Mr. Robert Bachert was the Contracting Officer's Technical Representative (COTR). The SBIR contractor is Vector Research, Incorporated (VRI); SofTech, Incorporated, in Dayton, Ohio was the subcontractor. This technical report was prepared by Dr. Susan Evans of VRI, with input from Ms. Nicole Ritchie of VRI and Mr. Ken Evers of SofTech, and satisfies CLIN item 0001.

INTENTIONALLY LEFT BLANK

CONTENTS

CONTENTS (Concluded)

LIST OF FIGURES

LIST OF FIGURES (Concluded)

1.0 INTRODUCTION AND BACKGROUND

As much as 70% of a system's life cycle costs are determined by decisions made during the concept exploration phase of system development (see U.S. General Accounting Office, 1985). A significant portion of these costs are associated with manpower, personnel and training requirements. Failure to consider human system integration (HSI) issues in the early phases leads to significant costs downstream. According to Graine (1988), for example, the combined cost of people and associated training requirements contribute close to 60 percent of the life cycle costs of a weapon system. The realities of shrinking Defense budgets and reduced manpower in the Services demand a thorough consideration of HSI at the very early stages of acquisition and throughout the process to minimize the costs and time required to proceed from Phase II onward.

Recently completed Air Force and Army studies have identified the Manpower, Personnel, Training, and Safety (MPTS) decision points in the acquisition process (Potempa and Gentner, 1989, and Rossmeissel et al., 1990). The challenges are to integrate useful and usable HSI planning tools into the early acquisition process, and ensure that the methods and supporting databases are compatible with design and analyses processes already in place.

Booher (1990) claims that much research and development work remains to be done before people, cost, and product data can be integrated by systems engineers as smoothly as hardware and cost data are today. The research of this Phase I SBIR defines the requirements for an integrated planning tool, which takes advantage of existing human factors, manpower, personnel, and training (HMPT) methods and interfaces them with existing design procedures. The remainder of this introduction defines the research objective in more detail, presents a summary of the weapon system acquisition process in light of human system integration[1] decisions, and lays out the remainder of the report.

1.1 RESEARCH OBJECTIVE

To develop human-system components for emerging weapon systems in a cost-effective manner, players in the early acquisition phases must be able to assess and evaluate the performance and life cycle costs of the human component of the system just as they do for more readily understood system components such as the avionics or power plant.

Specialized software which structures the vast quantities of design-related human factors, manpower, personnel, and training information should play an increasingly critical role in mission planning and systems design. Yet for the system designer these methodologies may appear inadequate, fragmented, or too cumbersome to be of use in their restrictivly short design timeframe. An analysis of these user information needs, the capabilities of current approaches, and the specific requirements for a comprehensive analytic approach is needed to ensure that designers of complex human systems will have useful, usable, and used automated planning tools in the future.

Organizations in Defense and civilian communities have been defining policy and promoting methods to consider the human impact. The Air Force's IMPACTS and the Army's MANPRINT directives are efforts to formalize the process and provide the design community with useful tools.

---

[1] DoD and Service specific directives have outlined requirements and procedures for considering the human factor in system acquisition. Within DoDI 5000.2 (Department of Defense, 1991b), it is referred to as Human Systems Integration (HSI). Within the Air Force, it is the Integrated Manpower, Personnel, and Comprehensive Training and Safety (IMPACTS) Process. The Army's Manpower Personnel Integration (MANPRINT) program is analogous. In all cases, potential human-system induced high drivers in six areas--human factors, manpower, personnel, training, health hazard, and system safety--must be identified and minimized prior to passing milestone review. For this report, the concepts (HSI, IMPACTS, and MANPRINT) are interchangeable.

Unfortunately, many of the existing tools take a bottom-up approach to the problem, starting with detailed task descriptions or requiring vast amounts of predecessor system data, which often precludes their use prior to Milestone I at the end of Preconcept Exploration.

What is needed is an accessible, compatible computer-aided system which starts with top-down system descriptions for functions, information requirements, and performance characteristics in increasing levels of detail, and supports the necessary design analyses. The system should facilitate function analysis and dynamic performance analysis, and produce output which supports the various reporting requirements for human system integration, and avoids costly decisions later.

The research objective of this Phase I SBIR was to establish the functional requirements for an effective design analysis and crew performance assessment methodology for starting during concept development and feeding subsequent phases. The resulting requirements provide direction for developing a prototype automated system in Phase II. Functional and information requirements of existing automated tools such as the Integrated DEFinition Language (IDEF) top-down structured analysis methodology, the Systems Analysis of Integrated Networks of Tasks (SAINT) simulation model, and various training and human performance models were evaluated, along with relevant non-automated approaches.

Among the questions answered in Phase I were:

- What are the information and decision requirements for human-system integration in the pre-Milestone I planning process?
- What planning tools are currently available? How do they meet the user needs?
- What new tools are needed?
- How can the HSI information databases be structured to tie different but necessary modeling approaches together?

This effort relied on lessons learned during the development of existing methods, and discussions with potential system users (e.g., training developers) to determine requirements to answer critical design decisions in a timely fashion. The system recommendations also consider the technology requirements and constraints of actual users. System affordability (i.e., cost to set up, train, and use) and accessibility are key concerns.

1.2 DEFENSE SYSTEMS ACQUISITION PROCESS

The principal objective of the defense systems acquisition process is to acquire and deploy effective systems in response to an identified deficiency or threat, or to capitalize on technology breakthrough, and thereby increase total force effectiveness. The objectives of the acquisition management decision makers are to influence and approve a cost-effective system acquisition program at key milestones, and to provide the information necessary to program and budget for the implementation of the system. This acquisition process is designed to develop, procure, and field a totally integrated and supportable system of technology, people and organizations, and to ensure that the complex system meets its cost, schedule, and performance goals (Rossmeissel et al., 1990).

The primary objective of DoD programs such as IMPACTS and MANPRINT is to influence system design so that the least-cost system makes the best use of the human resources that are available. Key decision makers must understand the importance of human issues (Manpower, Personnel, Human Factors, System Safety, Health Hazard, and Training) and design engineers must be willing to work with IMPACTS or MANPRINT practitioners to integrate these considerations into the engineering process. These perspectives must be considered from a total system perspective, and throughout the process, as shown in figure 1.

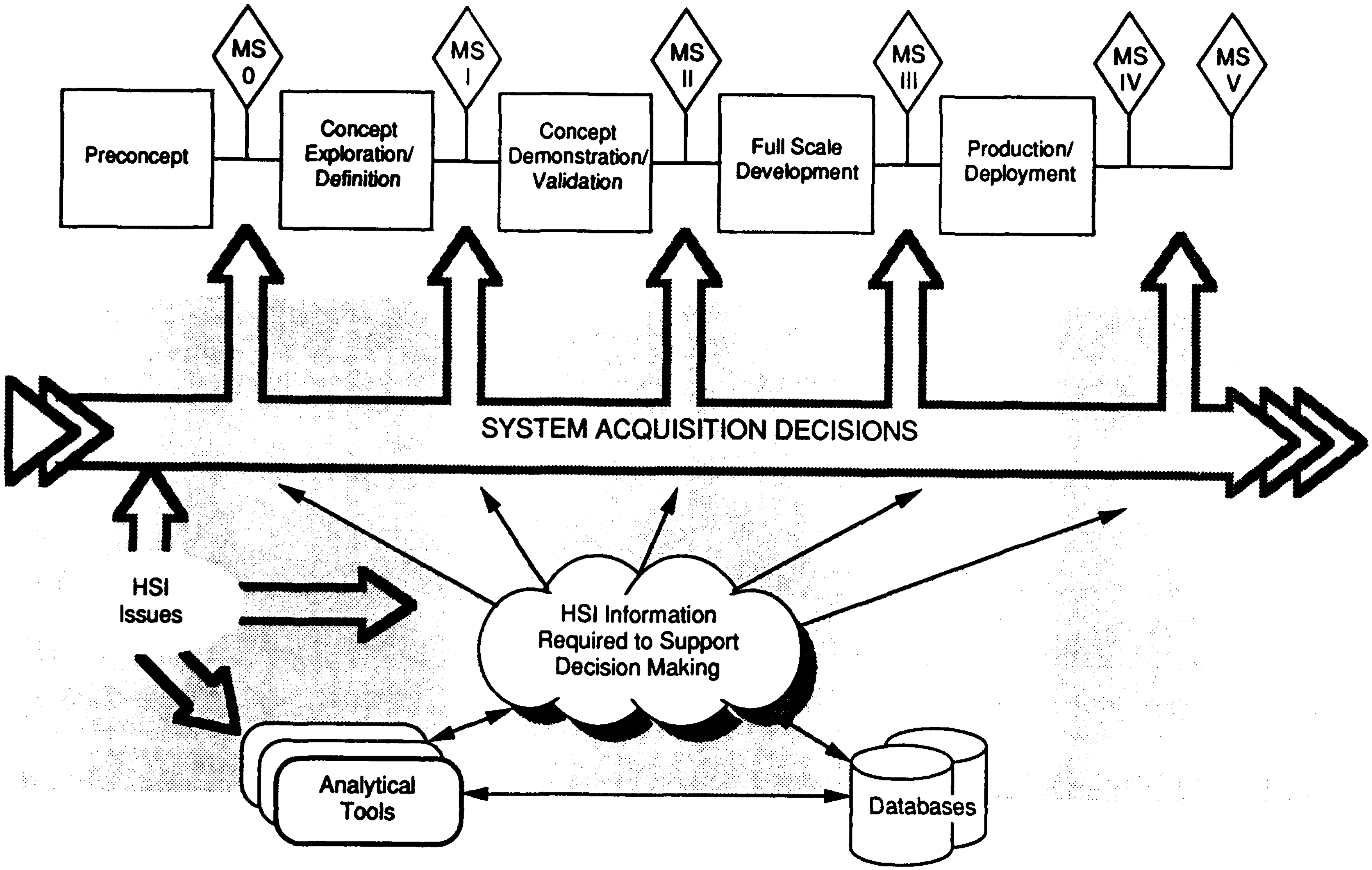


FIGURE 1: INTEGRATION BETWEEN HSI ISSUES, ANALYSIS TOOLS, AND DECISION MAKING CAPABILITY AND THE ACQUISITION PROCESS

The defense system acquisition process for conceiving, developing, acquiring, and fielding new systems is formalized in Department of Defense (DoD) Directives 5000.1, while the policies and procedures are specified in DoDI 5000.2 (Department of Defense, 1991a,b). The primary phases in the traditional, full-development acquisition process include Preconcept, Concept Exploration/Definition, Concept Demonstration and Validation, Full Scale Development, and Production and Initial Deployment. Milestones mark the transition between phases, with Milestone I occurring between the Concept Exploration/Definition and Concept Demonstration/Validation phases. These phases are described in figure 2, along with the principal HSI objectives in each phase. Key HSI activities include planning; requirements formulation; solicitation and source selection; and design and validation.

An HSI planning tool should aid in identifying HSI issues and decisions that must be addressed during the acquisition of the system and plan for activities and analyses for the remainder of the acquisition cycle. The tool should aid system planners in investigating HSI issues and determine whether:

- The total system will meet performance requirements.
- Available manpower will be sufficient to operate, maintain, and effectively support the total system.
- Personnel will have the skills and abilities to perform the tasks necessary to operate, maintain, and support the system.
- Personnel with the right skills, abilities, and training will be at the right place and at the right time to properly operate, maintain, and support the system.
- Individuals will perform the required tasks correctly under all operational and environmental conditions.
- Operation, maintenance, or support of the system will not result in safety or environmental hazard problems.

PHASE	ACTIVITIES	HSI OBJECTIVES
Preconcept	Prior to formally entering the Acquisition Process, the government defines needs for new or improved systems and identifies opportunities and constraints.	• Influence consideration of acquisition alternatives and requirements through identifying known or projected MPTS, health hazard or human factors constraints, opportunities and goals. • Identify and document HSI goals, constraints and opportunities.
Concept Exploration and Definition	Conceptual alternatives are identified and explored, and concept approaches are selected for further development.	• Identify and evaluate the characteristics of the alternative system design concepts that drive HSI requirements and costs or that may lead to human performance problems. • Identify the key issues, test and evaluation criteria, and design specifications and trades.
Concept Demonstration and Validation	Preliminary designs are verified and may include prototype hardware and software demonstration and early testing with troops; trade-offs among system characteristics are evaluated and system design specifications are developed.	• Influence the system design specifications through an assessment and evaluation of the preliminary design studies and trade-off analyses. • Develop the HSI planning factors necessary to field and support the system
Full Scale Development	The system design is finalized, tested, evaluated, and documented.	• Determine if HSI goals and constraints have been addressed adequately. • Identify and resolve any outstanding human performance or system safety issues. • Implement the actions necessary to field the system.
Production and Initial Deployment	Sustained production of the system is initiated, personnel and operational units are trained, associated support equipment is acquired and distributed, and logistical support is provided.	• Verify that HSI considerations have been fully integrated. • Identify HSI issues that need to be considered in future improvements. • Evaluate lessons learned.

FIGURE 2: SYSTEM ACQUISITION PHASES AND HUMAN SYSTEM INTEGRATION OBJECTIVES

1.3 REPORT ORGANIZATION

This report establishes the requirements for a pre-Milestone I HMPT planning tool, TACHSI: Tool for Analyzing Concepts in Human System Integration. Section 1.0 lays out the rationale for the tool in the context of the Defense Systems Acquisition Process. Section 2.0 describes the research methods employed during the Phase I SBIR. Section 3.0 reviews current automated approaches and methods which were considered for inclusion in the system requirements, and defines evaluation criteria for selecting specific methods. Section 4.0 defines specific system requirements, in terms of process diagrams, and user, functional, information and technology requirements. Finally, Section 5.0 presents recommendations for implementing a prototype system in the Phase II SBIR effort. Key prototype components are highlighted.

2.0 METHODS

Several sources were used to determine requirements for the HMPT planning tool TACHSI. Air Force (AF) and DoD publications and studies of HMPT issues in the system acquisition process were reviewed for potential requirements, complimentary approaches, and sources of tools to integrate. After analyzing the documentation of the current process, selected user groups were interviewed. Results of these interviews were compared against the documented procedures. Potential data sources were also investigated.

2.1 REVIEW OF AVAILABLE LITERATURE AND DOCUMENTS

Integrating HMPT into the system acquisition process is not a new topic of study. Recently completed studies, including some performed for the Air Force, were evaluated for insights into process requirements, user groups, the types of information needed to support the process, and the reporting requirements. Included among these were the Hay Systems study of MPTS done for the AF Human System Division (HSD/XR) by Rossmeissel et al. (1990); the development of an IMPACTS analysis architecture for concept exploration by Allan and Johnson (1991); surveys of human factors engineering tools applicable to MANPRINT and IMPACTS (Fleger et al., 1988; Booher and Hewitt, 1990); and the AF IMPACTS Process Handbook (Flint and Johnson, 1991).

The HSD/XR IDEF study of MPTS in the weapon system acquisition process described the issues and decision points that should be addressed to make the acquisition system more responsive to MPTS concerns. Each phase of the acquisition process was described in a top-down format through $IDEF_0$ diagrams and supplementary comments and explanations. The acquisition process was viewed as a series of activities and the MPTS related issues and decisions were linked to specific acquisition activities. Figures 3 and 4 show the two top-level $IDEF_0$ process diagrams resulting from this study[1].

The study by Allen and Johnson (1991) focused on MPTS assessment within concept exploration, and developed an analytic architecture for determining the human-centered concerns associated with conceptual designs during defense system acquisition. It defined a series of analytic steps, where each step was characterized by its inputs, transactions, and outputs, and generated IMPACTS decision data required for Milestone I. The architecture served as the foundation for a more detailed investigation in the future. It differs from the Hay study in focus and depth, focusing solely on pre-Milestone I issues.

One of the most complete surveys of human factors tools applicable to the system acquisition stages was performed for the Army in 1988 (Fleger et al.). The study identified 113 advanced tools in human factors engineering alone, but only 15 were shown to be operational and applicable to concept exploration phases in MANPRINT analyses. Several of the operational human factors evaluation (HFE) task models were considered in section 3.0 of this report.

A broader set of IMPACTS/MANPRINT tools and techniques were evaluated in Booher and Hewitt (1990). This analysis included the best of the HFE tools identified by Fleger et al., as well as the best of the MPT tools identified in a variety of Service-specific studies. Tools and techniques were summarized and classified by system acquisition

---

1 $IDEF_0$ is a diagramming methodology showing component parts, interrelationships among them, and how they fit into a hierarchical structure. $IDEF_0$ diagrams, which progress from the general to the more specific, are composed of boxes representing processes, arrows denoting data or objects, and labels which name the functions, data and objects. Input data flows into the process from the left; output leaves from the right. Control data enters the process from above, and mechanism objects are linked from beneath.

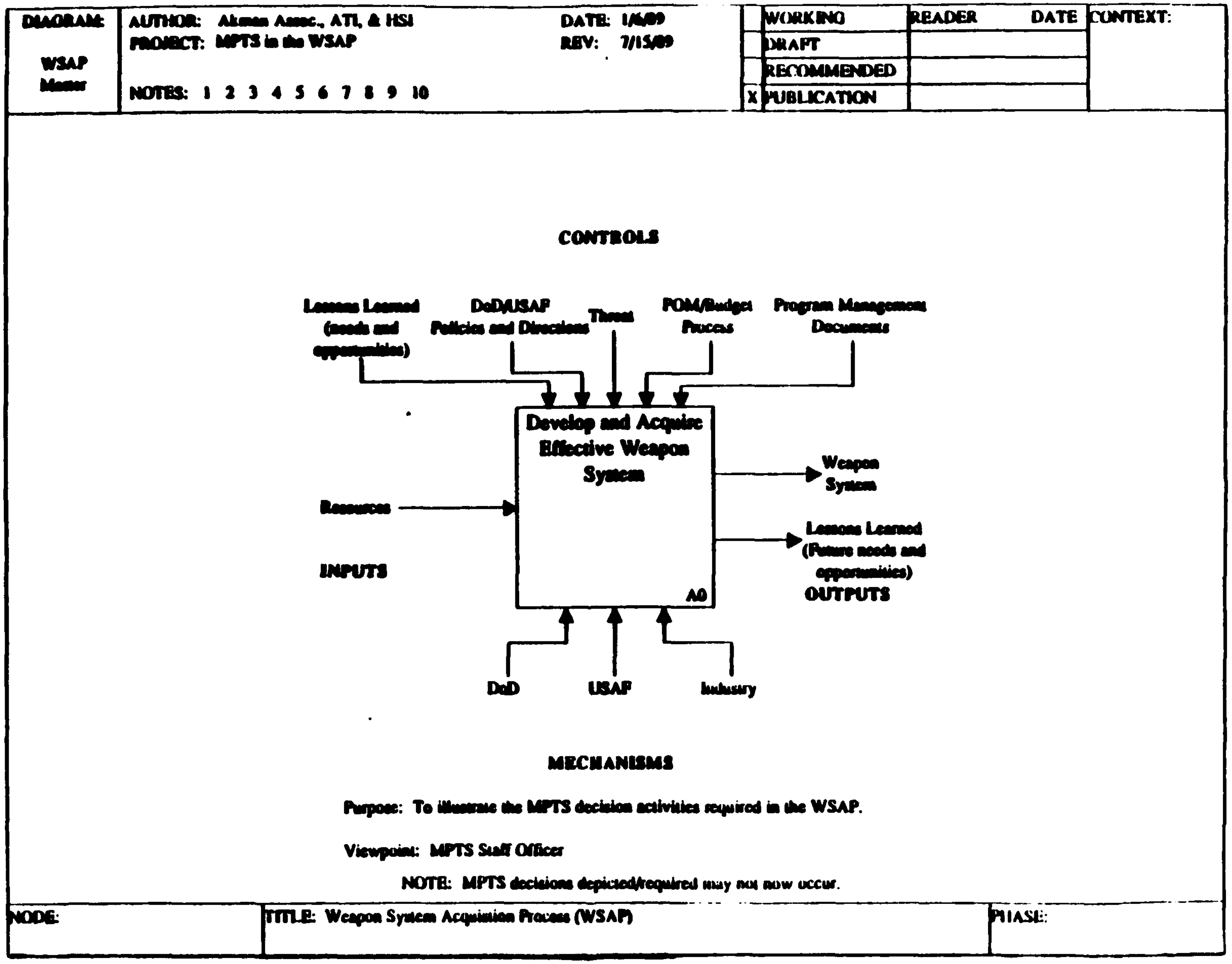


FIGURE 3: TOP-LEVEL IDEF PROCESS DIAGRAM FOR STUDY OF MPTS IN THE WEAPON SYSTEM ACQUISITION PROCESS (from Rossmeissel et al., 1990)

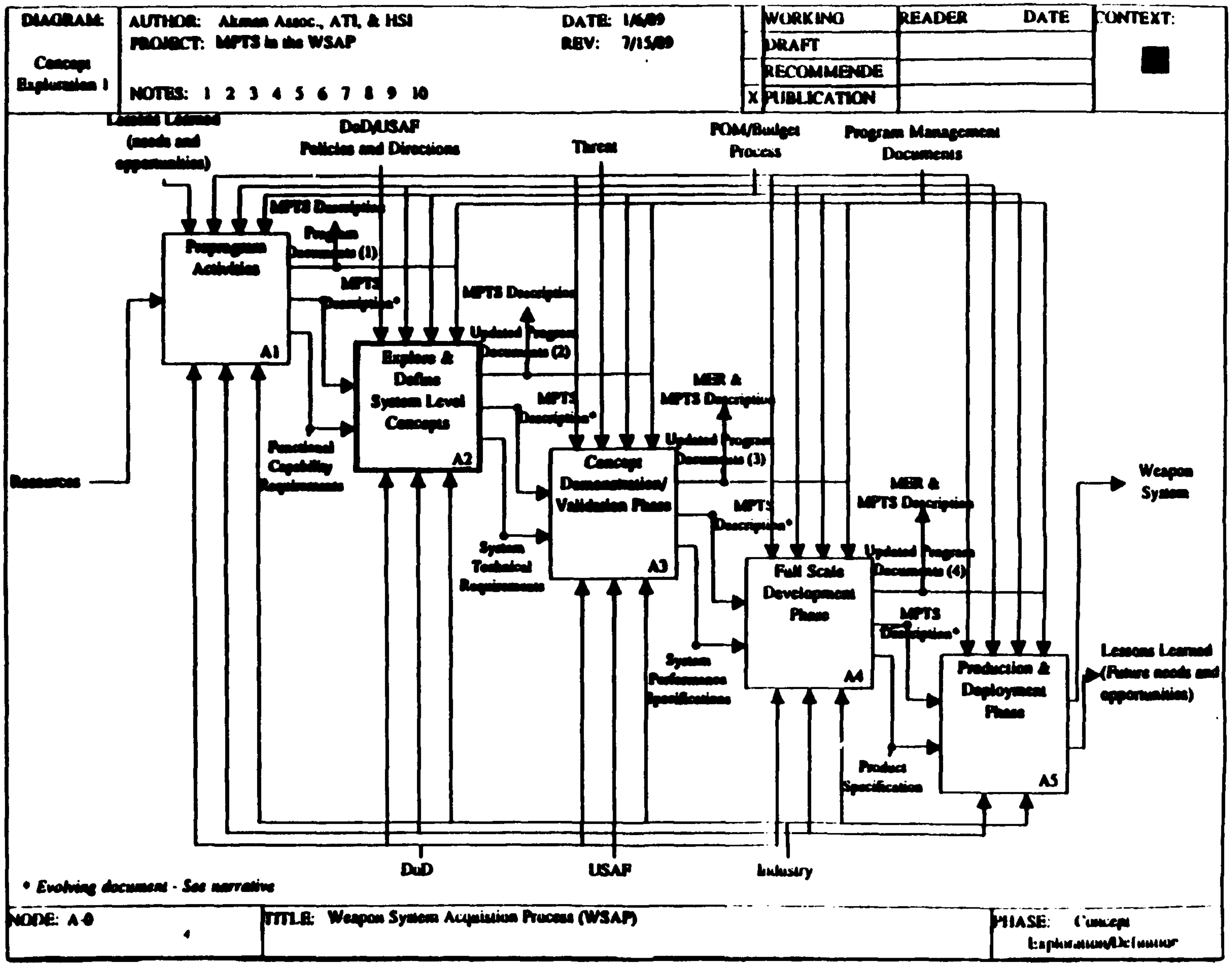


FIGURE 4: PRIMARY ACTIVITIES (PHASES) IN WEAPON SYSTEM ACQUISITION PROCESS WITH MAJOR INPUTS, OUTPUTS, CONSTRAINTS, AND MECHANISMS (from Rossmeissel et al., 1990)

phase, HSI domain, type of activity, analytical technique (task or comparability, simulation or statistical), theoretical basis (empirical or analytical), and availability.

The *IMPACTS Process Handbook* reflects the need for "how to" guidance on initiating the IMPACTS program and satisfying DoD requirements for front-end consideration of the human as an integral element of the system. It concentrates on a practical step-by-step approach, focused at the Air Force MAJor COMmand (MAJCOM) for identifying system-related human issues for initiation of a Preliminary IMPACTS Program Plan (PIPP) and subsequent integration of human issues into the Mission Need State-Oment (MNS) (Flint and Johnson, 1991). The handbook provides a detailed approach for early analysis to support identification of IMPACTS-related issues prior to Milestone I. It identified 17 databases as important resources for supporting IMPACTS analysis, and included brief descriptions of these databases.

2.2 INTERVIEWS WITH USER GROUPS AND DATA SOURCES

While the need to consider HMPT factors in the early stages of system acquisition has been stated for years, it has not yet become reality. Therefore, we interviewed potential users in the Training Special Program Offices (SPO), and members of the Logistics Directorate (XRL), at Wright-Patterson AFB, Ohio. The interviews determined the means by which users currently interface with the acquisition process, the type of information they use, data sources, time constraints, and any special procedures which should be considered in designing a planning tool.

These results were used to create a preliminary profile of user requirements in terms of functions, inputs, outputs, and constraints. The types of information available and desired, useful system functions, and workstation platform restrictions, were identified. Additional data on the time-criticality of information and the sequence of decisions in the planning process were determined. For Phase I, the scope of users was limited to those available at ASD at WPAFB. This was justified given the limited scope of players in the Pre-Milestone I planning process.

In addition to potential users, potential data sources such as the Crew Systems Ergonomics Information Analysis Center (CSERIAC) were investigated. CSERIAC's objective is to support DoD requirements for incorporating crew system ergonomics into the design and operation of military systems. Its mission is to provide ergonomic information analysis services to support research, design, and development of space, air, surface, and subsurface crew systems. Data from the *Engineering Data Compendium* (Boff and Lincoln, 1988), soon to be available electronically on laser disc, would be a source of human performance data to populate performance databases which support simulation models. The *Compendium* consolidated scattered research findings in a format intended to make it easier to interpret and apply. Data were considered for selection based on reliability, representativeness, generalizability, and relevance.

The planning tool should be applicable to later phases in the acquisition decision process, and contain compatible information wherever possible. These interfaces were discussed with members of the Acquisition Logistics (ALH) community.

2.3 DEVELOPING SYSTEM REQUIREMENTS

User interview results were used to produce a set of requirements defining the functions, information, and host platform needed in the resulting methodology. These were used as a benchmark for defining system requirements for a planning system which will be:

- useful,
- usable, and
- used.

Rather than build one more tool, the task of this research is to develop a structure for integrating existing tools which apply to the concept exploration phase of system acquisition.

Factors describing the user community, procedures, physical environment, and system integration issues were analyzed. The resulting planning system will function in the context of other planning activities within complex design activities. The proposed system requirements, described in section 4.0, are driven by principal information needs, but still consider the complete system context and existing tools, existing system interfaces, planned systems which will interface with the proposed system, departmental standards for interoperability, DoD policies and directives, and existing computer systems which support the project.

3.0 REVIEW OF CURRENT MPT APPROACHES

A wide range of automated HMPT methods and approaches exist or are in various stages of development. Comparative studies, conference proceedings, and process handbooks are full of descriptions. This section reviews current HMPT approaches with potential relevance to this phase of system acquisition, and identifies those for subsequent inclusion in the prototype planning tool.

Section 3.1 provides an overview of five classes of MPTS tools considered in this study; section 3.2 reviews candidate models considered in each class. Section 3.3 includes a discussion of tool selection criteria, based in part on criteria developed and applied to a Front End Analysis of an integrated Manpower, Personnel, and Training Analysis System (MPTAS) (Kerchner, 1991) and of those used in a decision table for MANPRINT tool selection (Booher and Hewitt, 1990). The Models described in section 3.2 are evaluated with respect to these criteria. Section 3.4 concludes with a demonstration of the TACHSI concept through an application of the Integrated Design and Engineering Analysis Language (IDEAL) methodology.

3.1 SCOPE OF MPTS TOOLS

Several classes of MPTS tools were candidates for inclusion in the TACHSI planning tool. These included:

- integrated design/analysis methodologies (e.g., IDEAL);
- top-down process decomposition and system description methods (e.g., $IDEF_0$);
- bottom-up task analysis/operator simulation methods (e.g., SAINT, MicroSAINT, Simulation Language for Alternative Modeling (SLAM));
- design-oriented human performance assessment (e.g., MIDAS, IDEAL Performance Database, Isoperformance); and

- training/Instructional System Development (ISD) requirements and cost estimation aids (e.g., ISD-LSAR DSS, and MIDAS-TAM).

The top-down process description method is missing from most HSI methods and approaches, yet it is an approach that is central to the system design community. This structured decomposition of processes, functions, or activities was formalized for the Air Force through the Structured Analysis and Design Technique (SADT), and later presented as the IDEF methodology (SofTech, 1981). It has been used by the AF to describe the MPTS issues in the acquisition process (Rossmeissel et al., 1990), but has not yet been included in any description of MPTS tools. Including this in the TACHSI planning tool will permit greater communication with the engineering community, and will enhance ease of use in the early acquisition phases.

The goal in this analysis is to scan across a range of classes of models, and select those with the best potential for complementing the combined functionality of the planning tool. An exhaustive search of all models is not included for several reasons:

- In many cases, it has been done before in both IMPACTS and MANPRINT domains, for human factors engineering and MPT analysis tools.
- In the interest of time, in-house expertise with models and analyses can be more effective than exhaustive searches to point out what does and does not work.

The TACHSI design leverages off of existing methodologies, simulation tools, and graphical human factors design systems in use or under development in the DoD community. As mentioned previously, examples exist for many of the components of this design system. The goal of the Phase I research is to identify those which have the greatest chance for successful integration, and to enhance the planning process.

3.2 HMPT MODEL CANDIDATES

Model candidates within each of the classes are presented below.

3.2.1 INTEGRATED DESIGN/ANALYSIS METHODOLOGIES

The current IDEAL modeling methodology is a proven general-purpose methodology for modeling a wide variety of system types (see Evers and Bachert, 1987). IDEAL's power lies in its capability to utilize knowledge-engineering techniques to collect, integrate, and verify system information from a team of people. It provides the capabilities to build a system simulation in a top-down, structured manner, in a notation that communicates and documents the system, and in a form executable on a computer. At this point it exists as a pencil-and-paper tool that relies on automated systems for the top-down hierarchical system definition and in-depth network simulation of system performance. These automated systems reside on personal computers and mainframes. The steps to transition between the functional system description and simulation are done manually, but lend themselves to automation with proper database methods. The performance database (PDB) is the key to the IDEAL concept, and is described in section 3.2.4.

Section 3.4 contains a sample application of IDEAL to the analysis of cockpit automation concepts and human-performance tradeoffs. This example will help to clarify how TACHSI could be applied to concept design.

3.2.2 TOP-DOWN PROCESS DECOMPOSITION

The IDEF technique is a tool for building descriptive models of system functions and data (SofTech, 1981). An activity modeling technique, it is a top-down hierarchical approach used to graphically illustrate system functions. $IDEF_0$ uses a top-down approach to produce a static representation of a system. This representation is in the form of an integrated set of diagrams consisting of boxes (defining system activities) and arrows (defining interfaces among the activities). The $IDEF_0$ model provides a graphic definition of the system structure in a top-down, gradual, controlled manner. Through an $IDEF_0$ model, a significant amount of analysis can be performed with regard to the static aspects of the system. A three-level $IDEF_0$ decomposition is shown in figure 5. The principal goal of $IDEF_0$ is to provide a structured approach for breaking a complex system into more elemental components for easier understanding. $IDEF_0$ has been used to model man-machine systems, the ISD process (Haines and Evers, 1990), automated message processing systems, database design, manufacturing capabilities, and software design. Automated $IDEF_0$ systems, such as Design/IDEF by Meta Software, exist on personal computers, and are strong candidates for inclusion in TACHSI. From the standpoint of human performance or MPT issues, however, IDEF falls short of representing task dependencies, temporal issues, and dynamic modeling or performance assessment.

3.2.3 TASK ANALYSIS/OPERATOR SIMULATION METHODS

To analyze the dynamic or operational aspects of the system, one must transform the $IDEF_0$ model into a dynamic model or simulation. This transformation must be accomplished in the most efficient way possible in order to:

- minimize the simulation development time;
- minimize the validation time;
- prevent a user from having to know two languages (ie., the $IDEF_0$ language and the simulation language); and
- provide a tight correlation between the models so that change in one model can be quickly reflected in the other model.

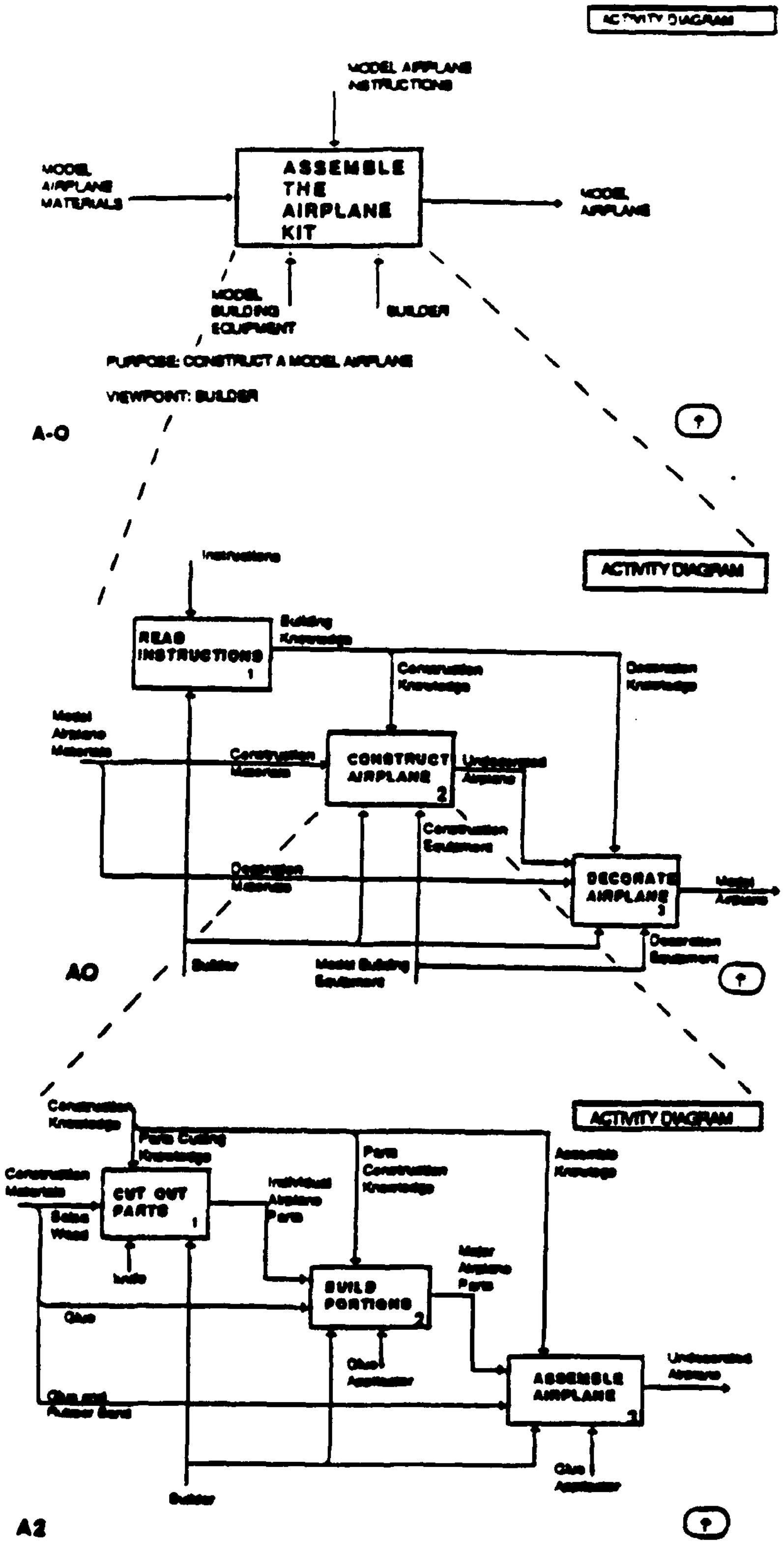


FIGURE 5: THREE-LEVEL IDEF0 PROCESS DECOMPOSITION (from SofTech, 1986)

Of the many simulation languages in existence, only three languages are candidates for integrating with the $IDEF_0$ notation. These languages are SAINT, Micro-SAINT, and SLAM. Each of these languages has been compared to the $IDEF_0$ technique from three perspectives: notation, input, and output.

As a point of reference, SAINT, Micro-SAINT, and SLAM are closely related, in the sense that Micro-SAINT was developed based on the same concept as SAINT, but with reduced capabilities. SLAM contains much of the original SAINT code, but its concept has been directed primarily toward modeling manufacturing systems. Therefore, the system perspective presented to the user by SLAM is more oriented toward queue analysis rather than activity and information flow analysis.

SAINT

SAINT is a network modeling and simulation technique designed to assist in the design and analysis of complex systems (Seiffert and Chubb, 1978). SAINT provides the conceptual framework for representing systems that consist of discrete task elements, continuous state variables, and interactions between them. An upgraded, customized version of SAINT, identified as C-SAINT, has also been developed. The two languages are identical in concept, but a few modifications have been made to C-SAINT to decrease the effort required to develop a simulation and to be able to monitor specific performance characteristics of a system. Within this discussion, SAINT will be used to refer to both SAINT and C-SAINT. Language implementations exist for IBM and VAX mainframes, as well as personal-computer platforms.

The network language notation of SAINT is based on a set of activities or nodes which are linked together to represent the flow of information or objects among the activities. Each activity is identified by a name and is characterized by a number of factors. These factors include items such as task performance time, task processing, definition, resources requirements, and branching-sequence definitions. Figure 6 shows a three-level SAINT activity decomposition.

The SAINT notation is fairly simplistic and very well suited for integration with the $IDEF_0$ notation. The primary benefits are: there is a one-to-one correlation between the $IDEF_0$ activities and the SAINT nodes; the mechanisms identified in the $IDEF_0$ model correlate directly to the resources in the SAINT network; and the interfaces among the $IDEF_0$ nodes are also represented in the SAINT network. The correlation allows for a very close visual correspondence between the two notations; and the additional dynamic information that is needed to generate the dynamic model can be overlaid onto the $IDEF_0$ notation without requiring a complex translation and interpretation process.

SAINT's interface is based on the old 80-column card format. Each record contains a well-defined set of information fields, with the fields separated by commas. This interface causes problems for those not familiar with SAINT, but is very effective for those who are proficient because there are no restrictions regarding the order in which records have to be developed or stored. Therefore, the SAINT interface provides an effective format around which an automated $IDEF_0$-to-SAINT translation program can be built.

The basic output of SAINT is minimal and is in table form showing resource utilization. With some minimal additional programming, the amount of output information can be increased significantly or be easily read into other application programs, such as a spreadsheet, which could provide a wide range of graphing and analysis capabilities.

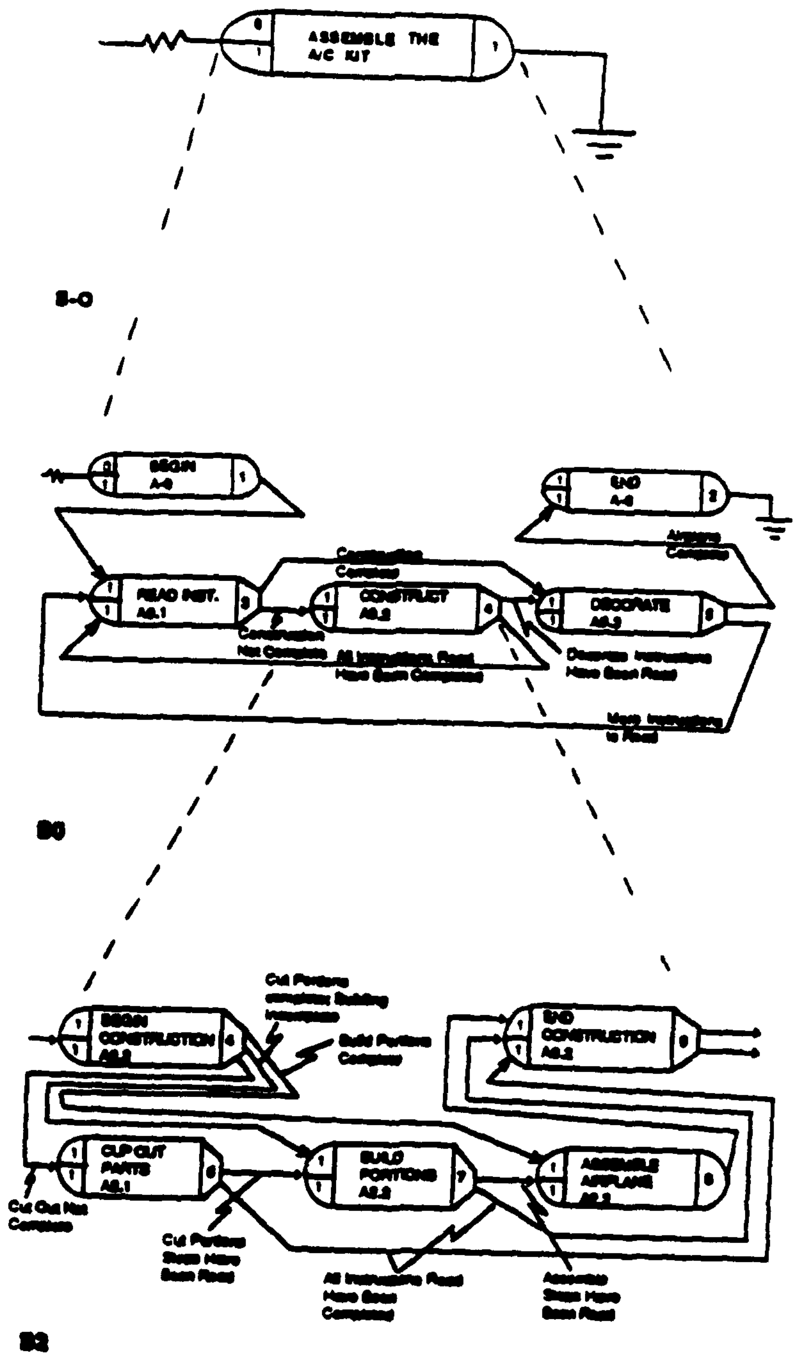


FIGURE 6: THREE-LEVEL SAINT ACTIVITY NODE DECOMPOSITION (from SofTech, 1986)

Micro-SAINT

Micro-SAINT was developed as a reduced version of SAINT for the IBM PC. The basic concepts of Micro-SAINT remain consistent with SAINT in terms of representing activities and information flow. Therefore, the notation correlation between Micro-SAINT and $IDEF_0$ is high.

The interface for Micro-SAINT has been modified from the 80-column format to a multilevel set of interactive prompting menus. This interface works fine for a novice modeler, but becomes a hindrance to the experienced modeler. More importantly, this menu interface becomes a significant problem in terms of developing an automated transition from $IDEF_0$ to Micro-SAINT. Not only will the translation program have to transfer information, it will also have to control the manipulation of the menus.

Originally, the output of Micro-SAINT was very similar to that of SAINT. However, the main output has been modified in terms of presenting the results using an animation concept. Some of the original tables still remain and could be read into other application programs for graphical information presentation.

SLAM

SLAM was developed as a follow-on to SAINT. SLAM contains some of the original SAINT code and retains some of the basic concepts of SAINT. However, the goals of SLAM were redirected toward that of the manufacturing environment. Within this environment, the emphasis is placed almost entirely on queue build-ups rather than task performance and information flow. As a result of the change in emphasis, the notation of SLAM was modified from the SAINT notation. SLAM's notation significantly reduces, if not eliminates, any reasonable correlation between $IDEF_0$ and SLAM.

SLAM retained most of the original 80-column-card input format, but also has a multilevel menu interface between the user and the fixed input format. This menu-driven interface has been well thought out and designed with respect to developing a SLAM model. However, when automating the transformation from $IDEF_0$ to SLAM, this menu interface will be a hindrance. A possible approach would be to remove the menu interface and go back to the 80-column format.

The primary outputs of SLAM are a couple of tables and an optional animated presentation of the output. Some additional tables can be generated through the development of user-specified code. The tables are formatted so that they can be transferred into other programs, such as a spreadsheet, which could provide graphic representation of the results.

Summary

To provide an effective linkage between $IDEF_0$ and a simulation, the two languages must be similar in concept and format. The brief discussion of the features of SAINT, Micro-SAINT, and SLAM have been summarized in figure 7. Within this table, "high" indicates that there is a high correlation between the $IDEF_0$ features and the simulation language features; "low" indicates no real correlation.

	Concept/ Notation	Input	Output
SAINT	High	High	Medium
Micro-SAINT	High	Low	Medium
SLAM	Low	Low	Medium

FIGURE 7: RATING OF THE CORRELATION BETWEEN $IDEF_0$ AND SIMULATION LANGUAGES

Because the three simulation languages are all variants of SAINT, the consistent rating of "medium" for the output is a reasonable expectation. The "lows" for input to Micro-SAINT and SLAM are due to their multilevel menus that will cause difficulty in generating an automated interface from $IDEF_0$ to the simulation. The "high" for SAINT's input is due to the procedural flexibility afforded through the 80-column format. The "low" for SLAM's concept/notation is caused by the switch from the task/information flow concept to a queue representation concept which does not align with the $IDEF_0$ activities. The "highs" for the SAINT and Micro-SAINT inputs are due to the fact that there is a one-to-one correlation between the $IDEF_0$ activity and the nodes within the simulation languages.

From this brief comparison, considering that the concept/notation and the input are much more critical aspects for the transformation than the output, SAINT stands out as the only language that can be reasonably pursued with respect to forming an effective translation from $IDEF_0$ to a dynamic simulation capability. To further strengthen the decision for SAINT, both Micro-SAINT and SLAM are proprietary packages which must be licensed, while SAINT is owned by the Air Force and is therefore in the public domain.

3.2.4 DESIGN-ORIENTED HUMAN PERFORMANCE ASSESSMENT

Three alternative approaches are discussed for human performance assessment. All are exploratory systems, with the Army-NASA Aircrew/Aircraft Integration (A^3I) program which is under development at NASA-Ames. The Isoperformance methodology was implemented for the Air Force as a prototype package as part of a Phase II SBIR effort. The Performance Database exists in concept form as a repository of data to support the IDEAL/IDEF/SAINT methodology. These are representative of the types of approaches possible for inclusion.

MIDAS

The A^3I Program is a joint exploratory development effort to advance the capabilities and use of computational representations of human performance and behavior in the design, synthesis, and analysis of manned systems (Smith, 1990). The program's goal is to conduct and integrate the applied research necessary to develop an engineering environment containing the tools and models needed to assist crewstation developers in the conceptual design phase. A major product of this goal is the development of a prototype Human Factors/Computer Aided Engineering system called MIDAS (Man-Machine Integration Design and Analysis System). This system provides design engineers/analysts with interactive symbolic, analytic, and graphical components which permit the early integration and visualization of human engineering principles. The MIDAS system is currently hosted on a number of networked Symbolics and Silicon Graphics workstations. This configuration provides the developers with considerable processing power and flexibility, but produces a system which is beyond the practical financial reach of many potential system users.

ISOPERFORMANCE

The Isoperformance methodology developed by Kennedy et al. (1989), allows the systems developer to fix systems effectiveness criteria and minimize the costs of MPTS and equipment through tradeoffs among cost factors. Isoperformance analyses are intended to be implemented as expert systems to aid in decision making through interactive computer programs for use by system designers. The user has access to a library of relevant information and system output consisting of a family of isoperformance curves. These curves are used to make comparisons among various local components relevant to systems development as they progress through the life cycle. A prototype implementation of the methodology was developed as a decision aid in specifying factors pertaining to training system design. Provided with the proper data, Isoperformance can provide program managers with a way to make resource allocation decisions.

PERFORMANCE DATABASE

The Performance Database (PDB) is a concept for storing necessary performance data to drive dynamic simulation models (e.g., SAINT) from limited static process decomposition models (e.g., $IDEF_0$). The PDB is populated via a separate interface, and contains five major categories of information. Each category may contain parameters for continuous and discrete models. Categories include Global System Characteristics, Scenario Specific State Conditions, Resource Attributes, Function or Task Characteristics, and Environmental Factors. The PDB concept differs from MIDAS or Isoperformance approaches in that it is not an analysis in itself, but a structure for storing information to support other analyses. Values for resource attributes, task characteristics, or environmental factors could as easily support training analyses as network simulations. Populating the database can be time consuming. Object-oriented techniques for specifying generic attributes and passing values to objects of similar classes should be investigated during implementation in Phase II to leverage off of previous designs and reduce set-up time.

3.2.5 TRAINING/ISD REQUIREMENTS

ISD/LSAR DSS

Instructional Systems Development (ISD) is a systems engineering approach to training that uses an iterative, building-block approach to determine the training system design requirements of a given weapon system. Specifically, ISD considers the relative need and appropriate methods to train each weapon system task and task element, and assesses the skills and knowledge of a target student population.

The Joint Service Instructional System Development/Logistics Support Analysis Record (LSAR) Decision Support System (DSS) provides an automated link for LSAR data to feed the ISD process as the LSAR proceeds during a weapon system acquisition (Dynamics Research Corporation, 1991). The automated ISD-to-LSAR data interface is a powerful technique that effectively integrates concurrent LSA and ISD analysis efforts. The automated link to LSAR data allows ISD analysts more time to effectively evaluate a weapon system's training requirements. The DSS provides easy access to current LSAR data, which enables training devices and materials to more accurately reflect dynamic weapon system designs. Also, automated ISD procedures eliminate labor-intensive data handling tasks and allow training analysts to effectively analyze training system requirements.

The ISD/LSAR DSS consists of LSAR data input routines, ISD analysis processes, and modified training design procedures that reflect and accommodate service-specific ISD procedures. The system includes utility functions that provide system security, database administration, report generation, and ISD analysis functions. All ISD analyses are documented on automated worksheets. Decision-support logic aids the user in selecting tasks that require training, selecting instructional settings and training media, sequencing instruction, and identifying training equipment fidelity requirements. The DSS presents LSAR and other analysis-related data to the analyst to assist in making ISD decisions.

MIDAS TAM

The MIDAS Training Assessment Module (TAM) is based on the Instructional System Design (ISD) methodology used in DoD (Smith and Banda, 1989). The TAM capitalizes on the Training Analysis Support Computer System (TASCS); but it also contains a more robust training domain knowledge representation and it concentrates on output pertinent to designers of both training systems and aircraft systems. The AI-based tool rapidly isolates the most significant training impacts of conceptual vehicles, and allows designers to ask pertinent "what-if" questions about changes to mission requirements, cockpit equipment, operator skills, or training budgets.

3.3 EVALUATION CRITERIA

Design evaluation criteria such as those described by Kerchner (1991) and Booher and Hewitt (1990) were applied to the various models under consideration. These included criteria for assessing the fully implemented system and the feasibility of development:

- Ease of use: the simplicity of application. Amount of training required to operate and use the system. Applicability to concept exploration phase of the acquisition process.
- Operating cost: resources needed to use the system. Data availability. Monetary resources as well as data requirements, equipment needed, personnel and time.
- Technical feasibility: the analytical methods, hardware, and software can be created or acquired and assembled in a manner to meet functional requirements, and to provide quality results for the intended application.
- Operational feasibility: the system can meet the principal operating requirements of its users, i.e., interface with other tools, and produce the required information in a timely, useful manner.

- Economic feasibility: development costs, consistent with budgetary constraints.

Candidates in each of the tool classes were evaluated against the criteria on a High-Low scale, with High denoting a good fit (i.e., easy to use, available data, low equipment costs, compatibility with design phase, etc.) and Low denoting hard to use (high training burden), high cost equipment, or high development costs, technical risks, etc.). Figure 8 presents the results of this evaluation.

3.4 DEMONSTRATION OF THE TACHSI CONCEPT THROUGH AN IDEAL EXAMPLE

Demonstrating a subset of the tools previously discussed may clarify how TACHSI could be applied to concept design. The IDEAL methodology includes many of the tools discussed in the preceding section. The example presented here demonstrates its use in conducting trade studies between human and automated components in an aircraft cockpit. Alternative concepts are modeled as different processors, i.e., mechanisms in $IDEF_0$ and SAINT, and with different performance functions in the performance database.

The IDEAL methodology is applicable to the analysis of many types of systems. To illustrate some of IDEAL's potential, the following example is provided. Consider a single-crew aircraft equipped with an intelligent subsystem called the pilot's associate. The avionics suite consists of three multipurpose video displays, an expert system database, and a protected-data manager (figure 9). During a mission, the pilot and pilot's associate are responsible for interrogating the aircraft's subsystems for status information. The interrogation requests are associated with either standard subsystem procedures or with specialized mission events. For example, a specialized event could be a lock-on indication meaning that the launch of an enemy missile is eminent.

CRITERIA	IDEAL	IDEF	SAINT	MICROSAINT	SLAM	MIDAS	PERFORMANCE DATABASE	ISOPERFORMANCE	ISD LSAR DSS	MIDAS TAM
Ease of Use										
Simplicity	M	M	M	H	M	M	M	H	M	H
Application to CE	H	H	H	H	M	H	H	H	M	H
Operating Cost										
Data Availability	L	H	M	M	M	L	L	L	M	L
Equipment Availability	H	H	M	H	H	L	H	H	H	L
Technical Feasibility	M	H	H	H	L	H	M	M	M	M
Operational Feasibility										
Tool Integration	H	H	H	L	M	H	H	M	M	H
Output Utility	H	M	L	M	M	H	H	M	H	L
Economic Feasibility	M	H	H	L	L	L	M	M	H	L

SAINT, as a stand-alone simulation model, requires considerable expertise to set up and interpret. Within the context of TACHSI, set-up would be automatic, and output would be run through a postprocessor to meaningfully format results.

H = High acceptance
L = Low acceptance

FIGURE 8: EVALUATION OF REPRESENTATIVE HMPT METHODS FOR INCLUSION IN TACHSI

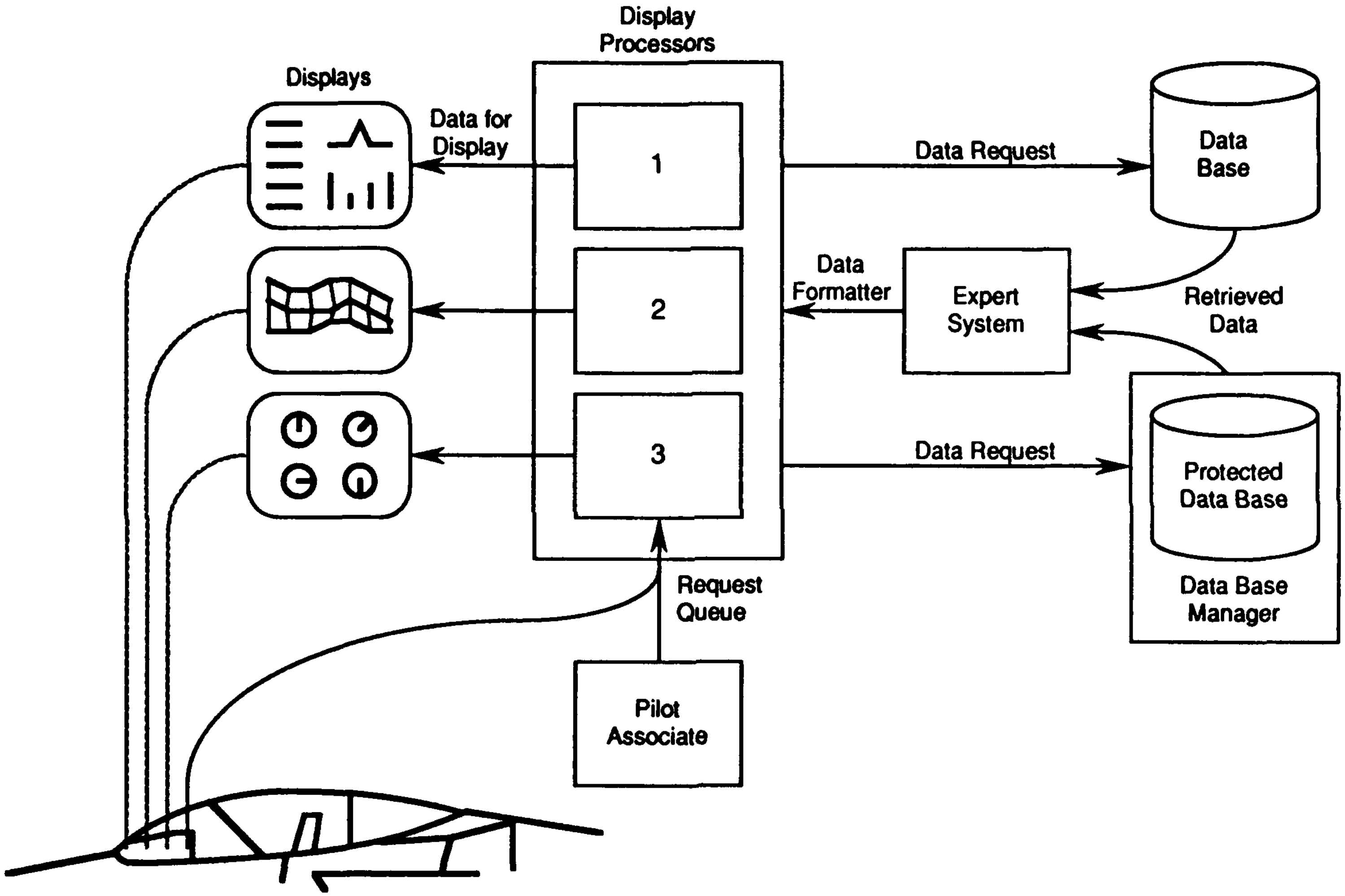


FIGURE 9: AVIONICS SUITE REPRESENTATION FOR IDEF DEMONSTRATION

In response, the pilot might have to determine the most effective type of countermeasure to be used.

Depending on the request, the processor associated with each display has to perform up to four tasks for each request. The tasks may be one of three types. The first is a simple request for information to be presented on the display. The second requires the display processor to access appropriate information, perform computations, establish the display format through an expert system, and display the information. The third requires the display process to access protected information through a data manager, obtain the display format through an expert system, and present the information using specialized graphics capabilities. Although both the pilot and the pilot's associate may request any of the task types, the pilot most frequently requests the specialized procedures, and the pilot's associate is most likely to make the simple display requests.

Once on the avionics bus, the requests for a single queue are assigned to the next available display processor. The request remains in the interface buffer while the display processor performs the first of the tasks within the request. If the request contains additional tasks, the display processor performs the appropriate actions. When all tasks for the request are completed, the request is deleted from the buffer, and the display processor waits for the next request in the queue.

The goal of the demonstration model is to determine if a proposed design is adequate to effectively process the requests for information made by the pilot and pilot's associate during a mission segment. Performance can be measured in various ways depending on the system's objectives, and which system aspects are being studied. For the cockpit simulation, the performance parameters have been selected to monitor the information flow through the system. These parameters include the number of requests that are waiting to be processed by various components of the avionics system, the length of time that the requests wait in queues for processing, the length of actual processing time, and the amount of time during the mission that the various system components are processing information.

The IDEAL methodology provides the approach for structuring the definition of the problem and for generating the simulation model. The $IDEF_0$ model of the system is provided in section 3.4.1 and the SAINT simulation network is provided in section 3.4.2.

3.4.1 $IDEF_0$ MODEL OF PILOT ASSOCIATE

This example contains a three-level IDEF decomposition. Level A-0 is the context level. Four processes are involved at level A-0, and three of these are decomposed further. Diagrams and associated descriptions are in figures 10 through 14.

3.4.2 SAINT MODEL OF PILOT ASSOCIATE

Within both IDEAL and TACHSI, the $IDEF_0$ model is the foundation for developing a simulation model of the system using the SAINT language. The development of the simulation model is a two-step process. The first step develops the basic network representing the system's process flow and the second step is to overlay dynamic characteristics onto the network. The full SAINT network for the pilot's associate example is shown in figure 15, spanning two pages.

The development of the simulation model begins by generating a top-level, single-node network based on the A-0 diagram. The next step is to detail this top-level model to correlate with the A-0 diagram. This level of the network, represented by the shaded area in figure 15, is bounded by the dummy nodes numbered 20 and 21.

The goal of the pilot support system being analyzed is to provide aircraft operational status information to the pilot. The information presented is categorized into two types. The largest amount of information provided to the pilot is that which indicates the operational status of the basic subsystems of the aircraft. The second type of information is that which indicates the mission events or the environment in which the aircraft is operating. This status information is collected from its sources within the aircraft, formatted, and presented to the pilot via a set of display units.

The requests which drive the displays are generated by both the pilot and the pilot's associate. The systems which work together to obtain, adjust, and display the information are the display processors, expert system database, and protected data manager.

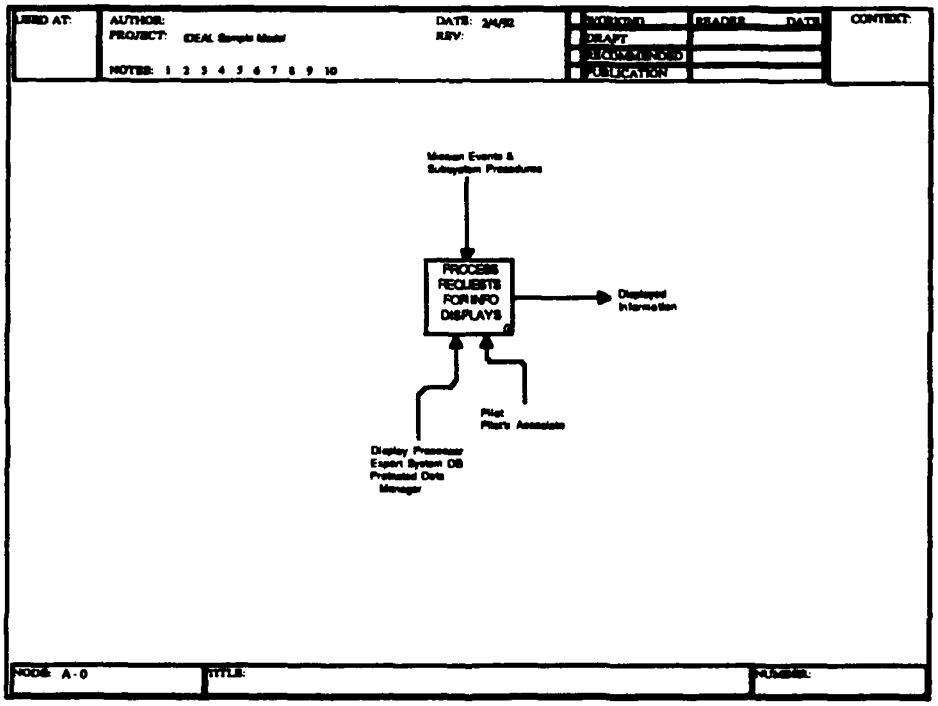


FIGURE 10: A-0 PROCESS REQUESTS FOR INFO DISPLAYS (CONTEXT)

The overall process involved in getting the required information to the pilot is represented as four major functions. It is assumed that before a request can be processed, it must be assigned to a dedicated display which, in turn, has a specific process associated to the display unit. Therefore, the first function results in the assignment of a specific request to a specific display unit.

Once the display assignment has been made, The Access and Prepare Info function interprets the requirements of the request, accesses the necessary information from within the aircraft, and establishes the guidelines for displaying the information. The Present Info to Pilot function manipulates the information to satisfy the requirements of the display format and then presents the information to the pilot using the display unit which has been assigned to the request.

Finally, when the current request has been fully satisfied, the display unit and the associated process must be freed so that it can be assigned to the next request in the queue.

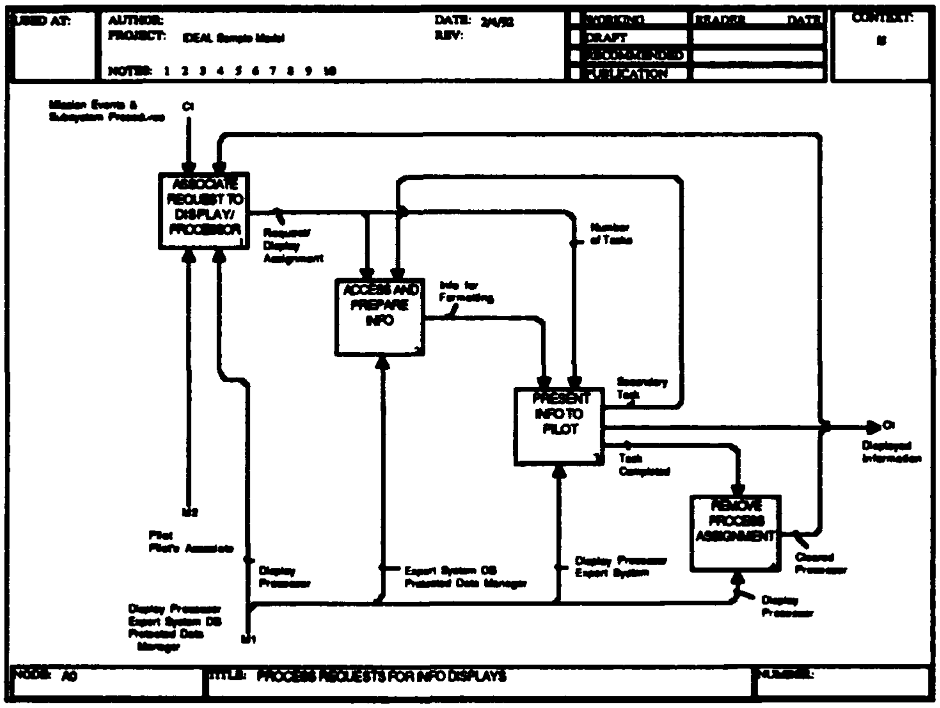


FIGURE 11: A0 PROCESS REQUESTS FOR INFO DISPLAYS

The requests for information are generated by two sources: the pilot and the pilot associate. These requests are based on a need for understanding the status of the standard aircraft subsystem operations or the status of specialized mission events define the environment that though which the aircraft is flying. As the requests are generated, they are placed in a queue to be processed by the aircraft's computer system. The first requirement for processing a request is to have a dedicated display and processor assigned to the request. If no display unit is available, the request in placed in a queue until a display does become available. The Track Display Availability function is responsible for monitoring the availability of the various displays and letting the Assign Request function know when a display unit is available for the next request.

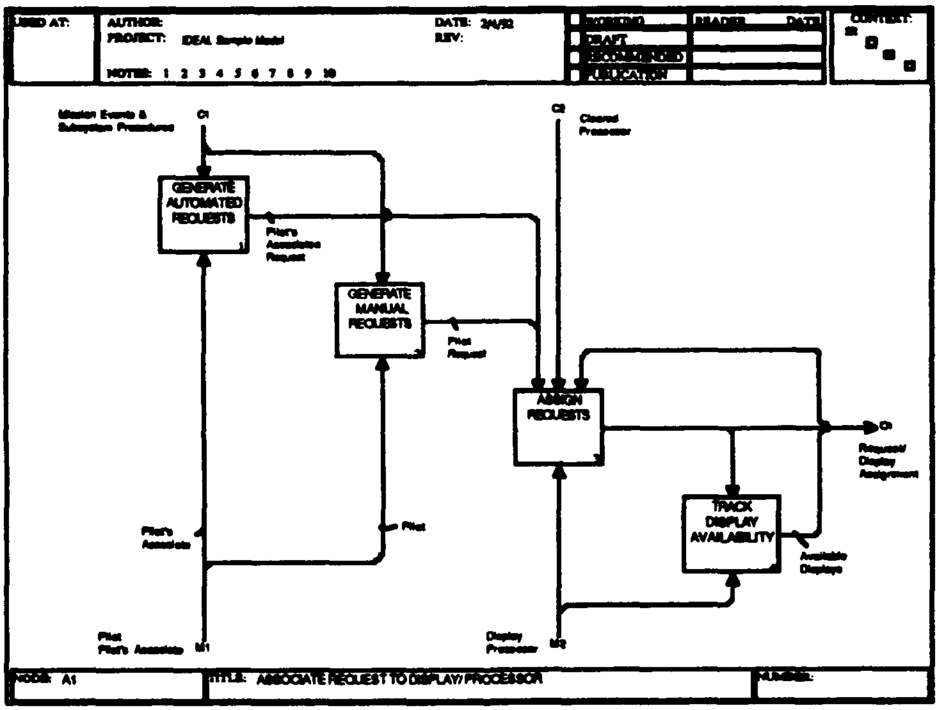


FIGURE 12: A1 ASSOCIATE REQUEST TO DISPLAY/ PROCESSOR

Once the next request in the queue has been assigned to a display unit, the system is ready to process the request. The first step is to identify the type of information that is associated with the request. The standard request involves information associated with the normal operation of the aircraft. For this situation, the assigned processor is able to directly access the necessary information and hand it over to the expert system for the actual processing and display. For the specialized information requests, the processor works through the data manager to access the appropriate information and performs the appropriate computations before handing control over to the expert system.

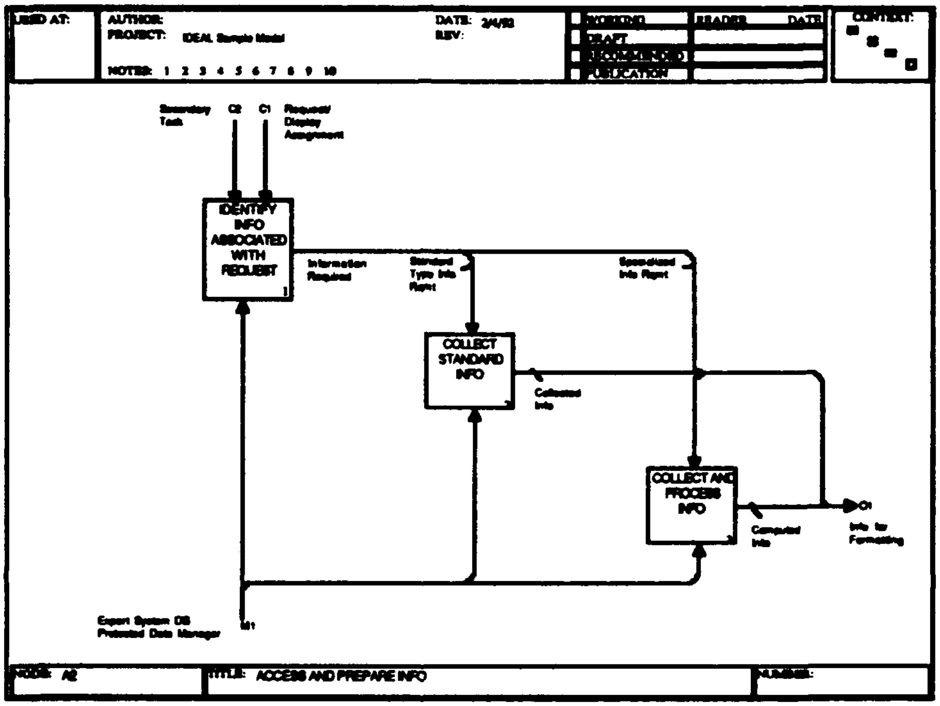


FIGURE 13: A2 ACCESS AND PREPARE INFO

If the information to be presented is the standard information, the display processor simply displays the information as represented within the pilot's request function. However, if the information to be presented is of the special type, the expert system first establishes the format that is to be used to display the information. Once the format has been established, the display processor then presents the information to the pilot.

As was defined for the requests, each request may involve up to four individual tasks. The Check If Request is Completed function represents the process of checking to verify that all the tasks have been completed. If the request is completed, control goes to the A0.4 task, which clears the appropriate subsystems so they are available for another request. If, however, more tasks remain to complete the request, control is returned to function A2.1 where task processing begins.

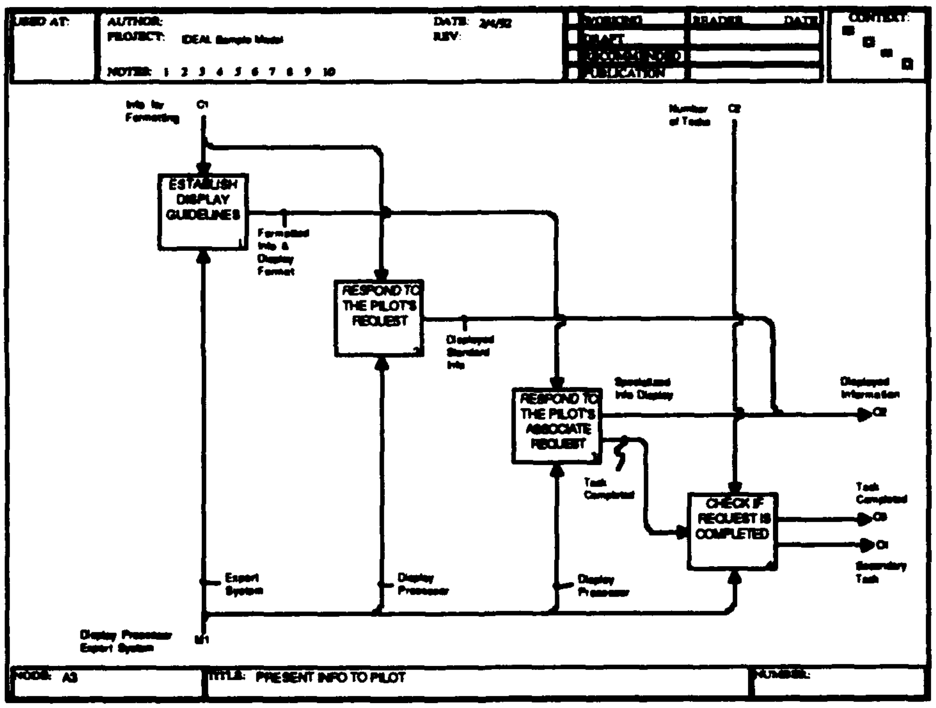


FIGURE 14: A3 PRESENT INFO TO PILOT

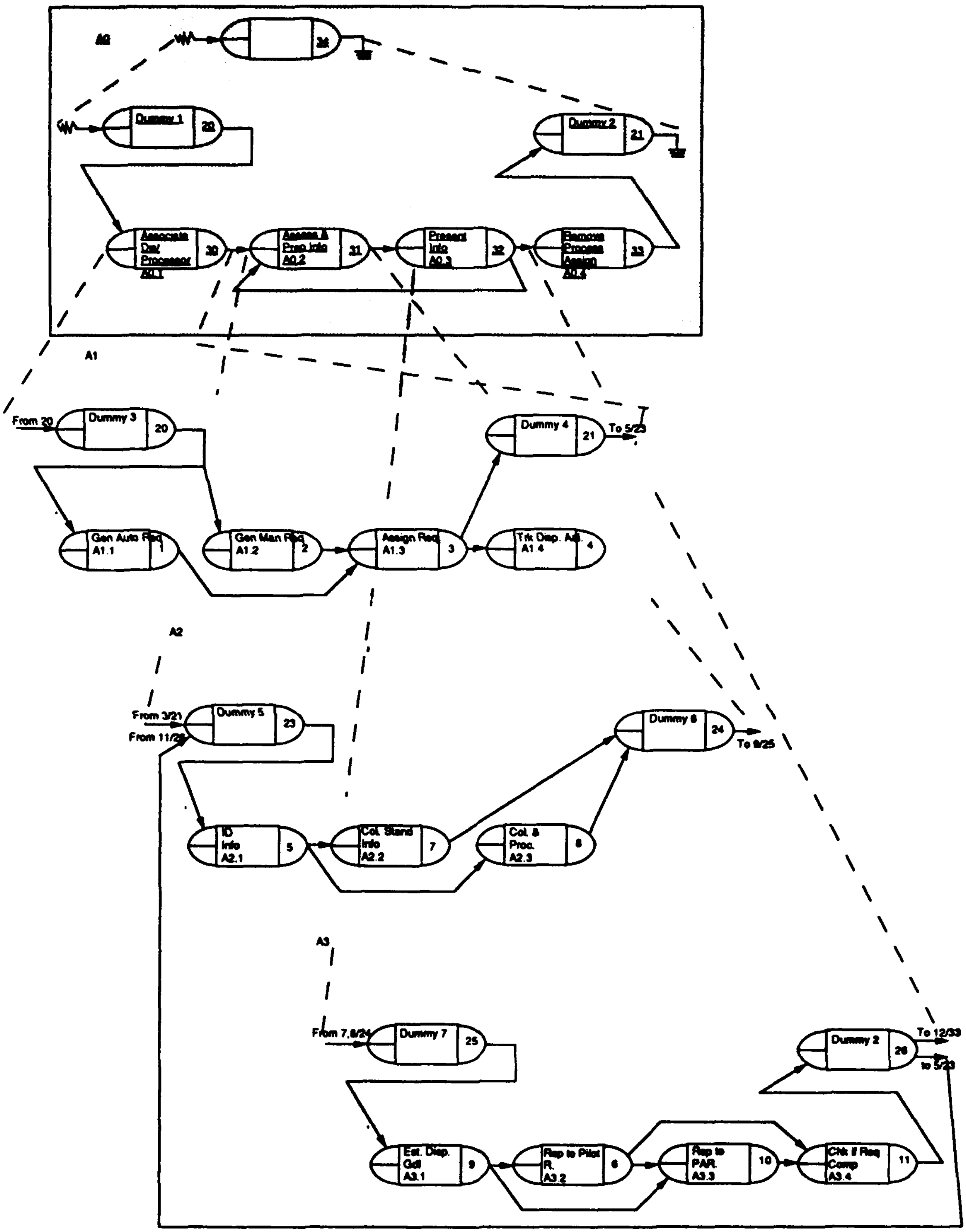


FIGURE 15: SAINT NETWORK NODES FOR PILOT'S ASSOCIATE CONCEPT DEMONSTRATION

For illustration within this example, the nodes 30, 31, and 32 are decomposed to one more level of detail. These nodes correspond to the A0.1, A0.2, and A0.3 functions of the $IDEF_0$ model. Figure 15 represents the next level of detail for the A0.1 function; region A2 represents the next level of detail for the A0.2 function; and region A3 represents the next level of detail for the A0.3 function. Each of these subnetworks is surrounded by dummy nodes in order to control the information flow so that the subnetworks can be represented in a modular manner.

When each of the simulation subnetworks are linked together as represented in figure 15, the correlation between the $IDEF_0$ and the SAINT network model is obvious.

The complete definition of the SAINT network requires that dynamic information be overlayed onto the basic network. This information is documented on the Performance Data Base (PDB) form illustrated in figure 16. One form is needed for each of the lowest level $IDEF_0$ functions which has a corresponding node in the SAINT network.

Within TACHSI, the SAINT nodes would be generated automatically, including the dummy nodes used to control the flow of information. The PDB form would be a pop-up form which would be populated from the PDB, when possible, or by the user in other cases.

3.4.3 SAMPLE OUTPUT

Within TACHSI, the SAINT simulation model is constructed to study the system's performance. Performance is measured in various ways depending on the system's objectives and the critical design variable. For this cockpit simulation, the designers are interested in determining if the avionics design is adequate to handle the requested load for a mission segment. To accomplish this analysis, several performance

FORM	Associate Display with Processor		
TITLE	Assign Request		
IDEF	A1.3	AUTHOR	
NODE	3	DATE	

FUNCTIONAL DESCRIPTION

PERFORMANCE TIME		MECHANISMS	MECHANISM CONDITIONS
DISTRIBUTION	Uniform	Display Processor	
MEAN			
MINIMUM	0.3		
MAXIMUM	0.6		
STD. DEV.			

PREVIOUS COMPLETIONS RQMTS.

PRIOR TASKS	OTHER REQUIREMENTS
1 2	

SUBSEQUENT BRANCHING

TASK NUMBER	BRANCHING LOGIC	MULTIPLE BRANCHING CONDITIONS
21 4		

NOTES

FIGURE 16: PERFORMANCE DATABASE FORM FOR PILOT'S ASSOCIATE CONCEPT DEMONSTRATION

metrics are used. The first metric is to look at the length of the request queue throughout the mission segment. This metric corresponds to the length of the queue at task 3. The information on queue length over time can be requested by TACHSI at SAINT run-time. Figure 17a graphs the queue length as a function of time, using the information in the Queue Monitoring Report file. It can be seen that the queue was never longer than four requests, and that was only for a very short time. The designers could then decide whether the queue lengths are acceptable.

Similarly, the queues of task 8 and 9 could be monitored to determine the queue lengths of the processors waiting to use the expert system and waiting for the data manager (figures 17b and 17c, respectively).

To study the length of time that the request waits in queue, a task interval statistic can be used to generate a measure of the time that the request (packet) waits in queue. The statistics gathered, and a histogram of the information produced by C-SAINT, are shown in figure 18. It can be seen that although the average wait in queue was about four seconds, one packet had to wait for over 19 seconds.

The Resource Utilization Report, figure 19, tallies the busy and idle times of each of the resources. This can be used as one measure of a resource's workload.

The possibilities of other kinds of metrics one might collect are almost endless: numbers of requests serviced by each display processor can be collected using Number Statistics on task 13, 14, and 15; duration of each separation transaction can be collected with Interval Statistics between task 5 and task 11; individual requests can be traced

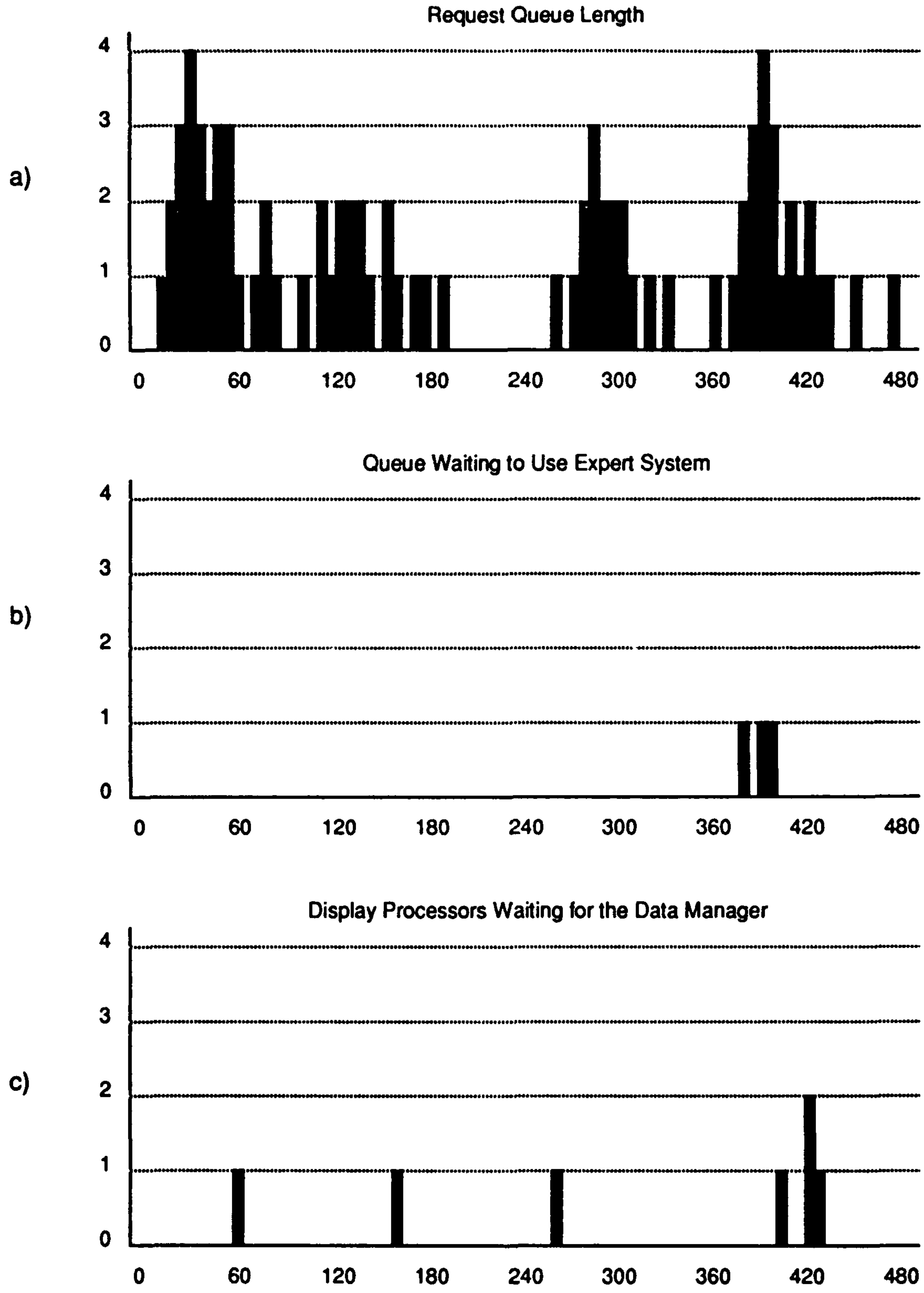


FIGURE 17 a,b,c: DISPLAY PROCESSORS WAITING FOR THE DATA MANAGER

Task Num.	Task Label	Stat Type	Collection Point	Average Value	Standard Dev.	Number of Obs.	Min Val.	Max Val.
3	Next_Req	Int	Sta	4.074	5.41E	72	000	19.4

Obsv Freq	Rela Freq	Cuml Freq	Upper Cell Limit
31	0.431	0.431	0.00
5	0.069	0.500	0.20
12	0.167	0.667	0.40
4	0.056	0.722	0.60
4	0.056	0.778	0.80
4	0.056	0.833	0.10
4	0.056	0.889	0.12
3	0.042	0.931	0.14
0	0.000	0.931	0.16
3	0.042	0.972	0.18
2	0.028	0.100	0.20
0	0.000	1.000	0.22
0	0.000	1.000	INF
72			

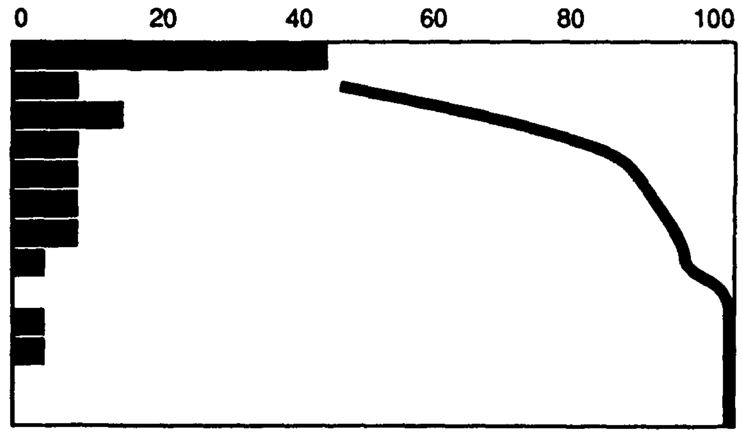


FIGURE 18: TIME IN QUEUE TASK SUMMARY AND HISTOGRAM

Resource Number	Resource Label	Total Time Busy	Total Time Idle	Fraction of Time Busy	Fraction of Total Time
1	Unit1	397.3	90.8	8139	1861
2	Unit2	373.7	114.5	7655	2345
3	Unit3	343.0	145.1	7027	2973
4	Proc_1	379.6	108.5	7776	2224
5	Proc_2	357.1	131.1	7315	2685
6	Proc_3	328.8	159.4	6735	3265
7	Expert_S	97.5	390.6	1997	8003
8	*Prot_Inf*	97.1	391.0	1989	8011

FIGURE 19: RESOURCE UTILIZATION REPORT

through the system using the Detailed Iteration Report; and information on the packets at each task can be collected using the Information Monitoring Option for that task.

4.0 SYSTEM REQUIREMENTS

The HSD/XR IDEF analysis of the MPTS issues in the system acquisition process (documented in Rossmeissel et al., 1990), and a review of the more promising HSI tools, support the system requirements presented in this section. The $IDEF_0$ methodology, in addition to being proposed as a component of TACHSI, is used as a system description tool to identify the inputs, outputs, controls, mechanisms, and system functions from the viewpoint of an HSI analyst. The following sections describe the TACHSI environment through hierarchical IDEF diagrams, and outline the intended functions, users/mechanisms, information, and hardware environment in which it will be used.

4.1 TACHSI PROCESS DESCRIPTION

TACHSI, a Tool for Analyzing Concepts in Human Systems Integration, supports the system acquisition process through a family of flexible MPTS methods and databases. Tool application is focused during the concept exploration phase, but its utility lends itself to other phases as well. Most of the components exist as independent automated methods, and the TACHSI framework provides structures for linking the methods through shared information flows and a common user interface.

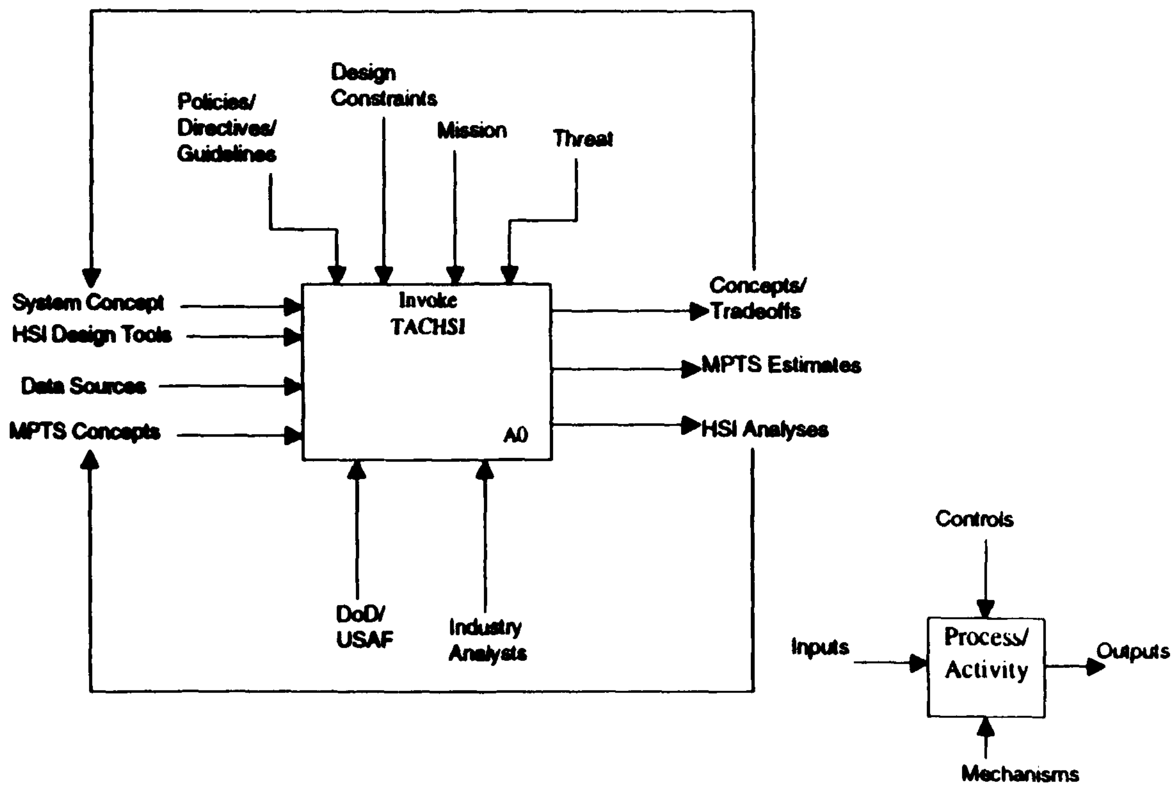
The master context in which TACHSI is used is shown in figure 20, an $IDEF_0$ diagram consisting of one process box, with several inputs, outputs, mechanisms, and controls. Note that the system provides feedback to design alternatives through the results of concept trades, and HSI analyses. Mechanisms include persons/organizations in government and industry. Controls or constraints to the analysis include official policies, directives and guidelines, and resource constraints.

USED AT:

AUTHOR: S. Evans
PROJECT: TACHSI Requirements Document
DATE: 2/5/92
REV:

NOTES: 1 2 3 4 5 6 7 8 9 10

X	WORKING	READER	DATE	CONTEXT:
	DRAFT			
	RECOMMENDED			
	PUBLICATION			



Purpose: To structure the TACHSI tool for concept analysis.
Viewpoint: HSI Engineer/System Developer.

NODE: A-0 | TITLE: | NUMBER:

FIGURE 20: MASTER TACHSI PROCESS DIAGRAM (LEVEL A-O)

Note that the role and description of mechanisms is very important within TACHSI. They become interchangeable agents, and permit great flexibility in evaluating alternative designs.

The contents of the inputs, outputs, mechanisms, and controls for the TACHSI context diagram are analogous to those feeding/resulting from the Concept Exploration process box in the HSD/XR IDEF model.

Integrating existing tools under a common architecture was preferred to developing a completely new approach. Properly designed, a modern architecture will efficiently bridge interconnections among models and methods. The use of existing tools such as IDEF and SAINT within the integrated architecture increases the operational feasibility, since the tools have some credibility established. The structure permits flexibility in adding new tools to the architecture. As the tool kit expands, the user will be able to analyze a wider range of issues (e.g., concept issues such as mission effectivenes), and a larger class of users, beyond just the MPT community, may benefit. An intelligent interface among the tools also reduces the user-training burden.

4.2 FUNCTIONAL REQUIREMENTS

Figure 21 contains a second-level IDEF process decomposition of TACHSI. The activity boxes correspond to the basic functions provided by TACHSI. Figure 22 contains a hierarchical description of the basic system functions, corresponding to decomposed IDEF activity boxes.

4.3 INFORMATION REQUIREMENTS

INPUTS

Specifying task data is the primary driver in preparing for many MPT analysis in TACHSI. The desired level of task decomposition, the

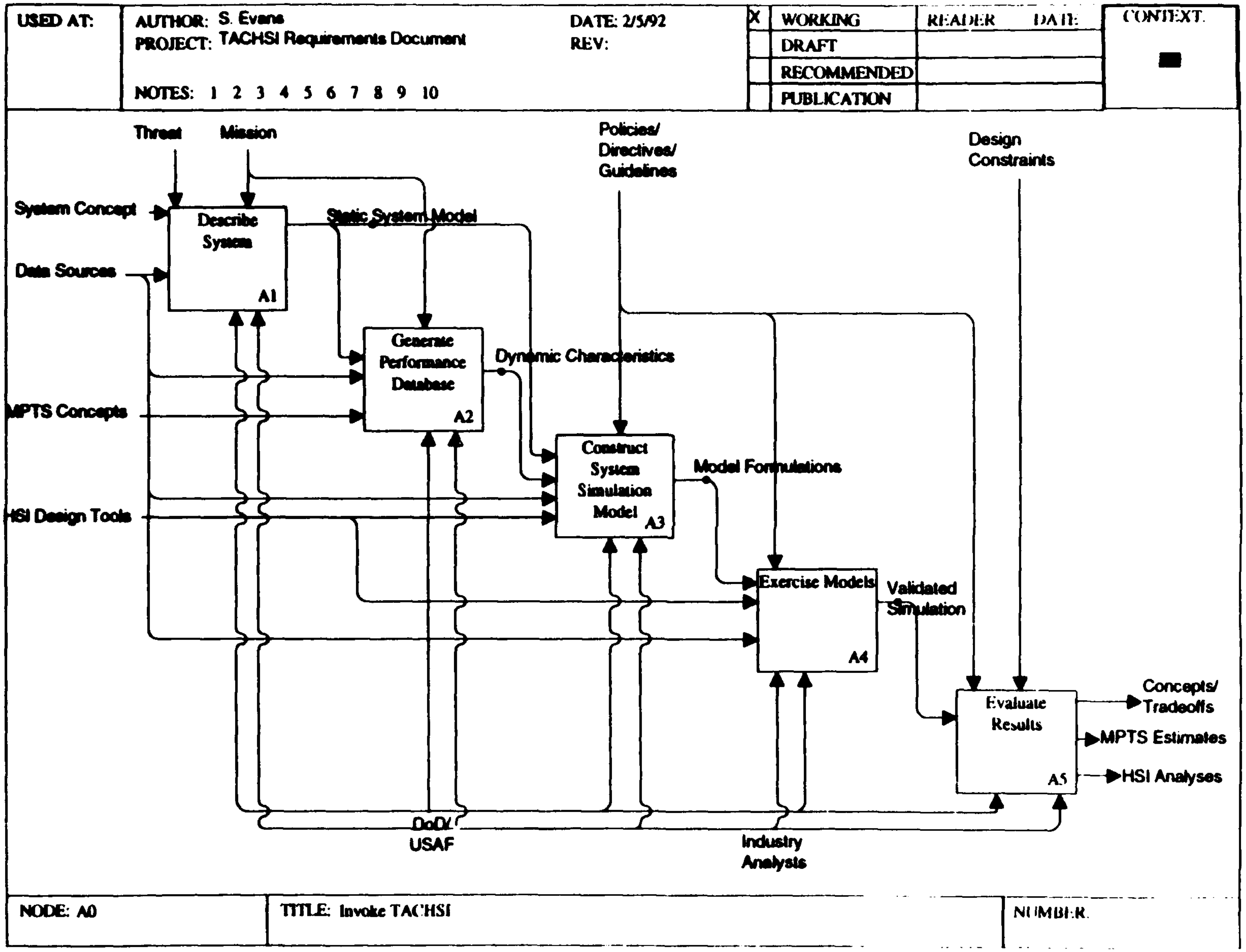


FIGURE 21: LEVEL AO TACHSI PROCESS DIAGRAM

[A0] Invoke TACHSI

- [A1] Describe System
  - [A11] Review Predecessor System
  - [A12] Define Process Decomposition
  - [A13] Define Analysis Objectives
- [A2] Generate Performance Database
  - [A21] Review Existing Models
  - [A22] Define Synamic Task Information
  - [A23] Define System Information and Resource Attributes
  - [A24] Define Environmental Conditions
- [A3] Construct System Simulation Model
  - [A31] Define Human Operator Model
  - [A32] Define Machine Model
  - [A33] Select Simulation Techniques
- [A4] Exercise Models
- [A5] Evaluate Results
  - [A51] Select Output Views
  - [A52] Evaluate Against Criteria
  - [A53] Recommend Change/Complete Analysis

FIGURE 22: THREE-LEVEL FUNCTION DECOMPOSITION FOR TACHSI

source of data (i.e., access to predecessor system), or the presence of expert system aids will significantly alter the time needed to describe the nature of HSI under study. Consistency across descriptions is necessary to ensure use across analysis models. The IDEF/SAINT activity task linkage is locked, but the link to LSAR data for the ISD/LSAR DSS will be harder to enforce without a predefined task description vocabulary.

OUTPUTS

TACHSI includes capabilities to prepare both standard and ad hoc analysis reports. The library of standard reports will evolve as tools are added and user requests expand. Contents of standard reports include:

- design/analysis graphs supporting system and MPT tradeoff studies, high drivers identification, and cost assessment will be standard. SAINT simulation output will be stored in databases for subsequent analysis. Examples include mechanism/resource utilization;
- process diagnostic aids such as user audit trails, model activity logs, inconsistencies in information flow, or flags pointing to inconsistencies in HSI model structures; and
- analyses formatted to interface directly with IMPACTS reporting requirements (e.g., IMPACTS Program Plan, etc.)

Reporting and charting features represent the primary communication device among system developers throughout the acquisition process. TACHSI reports and graphs will support this process.

4.4 SYSTEM USERS

The HSD/XR IDEF study identified various mechanisms and their interactions at each process activity. In the pre-Milestone I activities (decompositions of A1 and A2 activities) where system level concepts are explored and defined, the Air Force players include the MAJCOM, Training command (ATC), ASD planning organizations and SPOs if they exist, the support commands, and the AF Office of Technical Assessment (AFOTA).

Industry/contractors would also be mechanisms. User involvement for the three level-two concept exploration activities which drive MPTS decisions are shown in figure 23.

Mechanisms/Users	A21 Select & Award Execute Concept Explore/Define Constraints	A22 Evaluate & Select Alternate Concept Approaches	A23 Develop/ Update Program Documents
Air Force			
• Air Force Office of Technical Assessment		X	
• MAJCOM	X	X	X
• ASD/XR	X	X	X
• Air Training Command (ATC)		X	
• Support Command	X	X	X
Industry	X	X	X

FIGURE 23: MECHANISM IN MPTS-DRIVEN ACTIVITIES IN CONCEPT EXPLORATION

4.5 PLATFORM REQUIREMENTS

No single platform configuration stands out as the overriding preferred choice. Tool users prefer a platform with a graphical windows and mouse interface, network access to shared databases, and device-independent applications. Most existing HMPT applications provide few of these capabilities, with most residing on non-networked PC/DOS platforms. The ISD/LSAR DSS is a networked DOS application.

The move toward open system architectures over the next few years will make it easier to comply with these preferences. In the interim, however, the platform and compatibility requirements listed in figures 24 and 25 are starting points.

Hardware	Macintosh or UNIX
Software	Windows Environment • X-Windows on UNIX • Mouse Interface
Database	Geometric/Graphic Object Database • 4th Dimension RDBMS on Mac • SYBASE or Informix on UNIX

FIGURE 24: TACHSI PLATFORM REQUIREMENTS

Computer-Aided Acquisition and Logistics Standards (CALS) Compliance

Data Interchange Standards

- IGES - International Graphics Exchanges Specification (for two and three dimensional geometry)
- STEP - ISO Standard for the Exchanges of Product Model Data
- PDES - Product Data Exchange Standards

Open System Standards

- GOSIP - Government Open System Interconnection Profile
- POSIX - Portable Operating System Interface for Computing Environments

FIGURE 25: COMPATIBILITY REQUIREMENTS

Several data standards apply to product, mechanical design and logistics data. These include PDES, IGES, STEP, and CALS.

Standard interfaces to permit product data exchange with models and engineering design systems should conform to PDES (Product Data Exchange Standards). This will permit communication between different CAD/CAM/CAE design systems among government and contractor sources/users.

The Initial Graphics Exchange Specification (IGES) defines a neutral format for two-dimensional and three-dimensional geometry. Translators convert proprietary internal data formats into and out of the IGES format, but fall short of complete geometry transfer between systems without human intervention.

The ISO Standard for the Exchange of Product Model Data (STEP), in conjunction with PDES, addresses all phases of the product life cycle, with information on shape/size, configuration, function, and physical and operational characteristics.

Use of product data exchange standards will ensure compliance with CALS requirements, as MilStd 1840A is applied to new DoD procurement contracts. This will also permit cost-effective communication of product data (e.g., system geometries, subassembly locations and characteristics) among government and industry/contractor personnel. Access to graphical data will facilitate analysis by operator graphic and CAD models, and ensure that analyses are performed on the most current, consistent, and accurate product description data.

5.0 RECOMMENDATIONS

This section describes the process to be employed in Phase II for developing the demonstration prototype for the Tool for Analyzing Concepts in Human Systems Integration (TACHSI). Section 3.1 presents an overview of the approach, and sections 3.2 through 3.5 detail the approach used in each of the four Phase II tasks.

5.1 OVERVIEW OF APPROACH

The overall approach to developing the demonstration prototype for TACHSI will apply a proven system development philosophy and standards, procedures, tools, and techniques employed in the past. These include state-of-the-art software life cycle methods, open system standards, structured analysis and design, joint application development (JAD) and rapid prototyping techniques, and data modeling techniques. The basic development approach follows the steps: Design, Develop, Test, and Document. TACHSI design activities are encompassed in Task 1; development and test in tasks 2 and 3. Documentation is included throughout the process, starting with specifications in Task 1, followed by ongoing updates during development, and concluding with the final form of each in Task 4.

The context and first-level decomposition of the TACHSI design approach is presented as two $IDEF_0$ diagrams in figures 26 and 27, respectively. Note that right-pointing arrows represent inputs, left-pointing arrows denote output; down-pointing arrows are constraints or controls within the process. The mechanism, the VRI development team, applies to all processes.

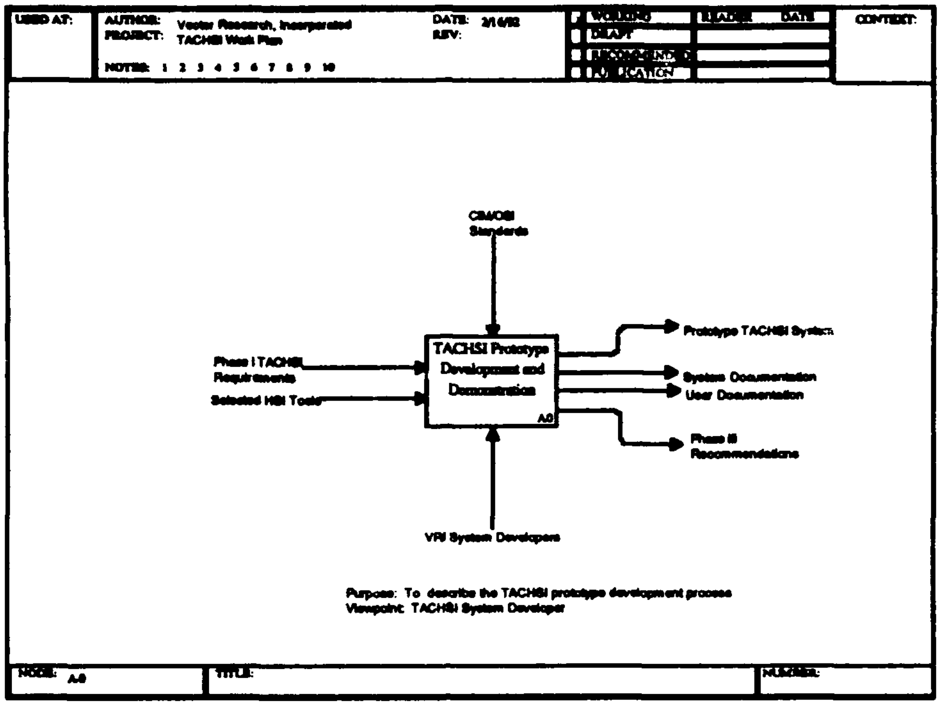


FIGURE 26: IDEF CONTEXT DIAGRAM FOR TACHSI SYSTEMS DEVELOPMENT APPROACH

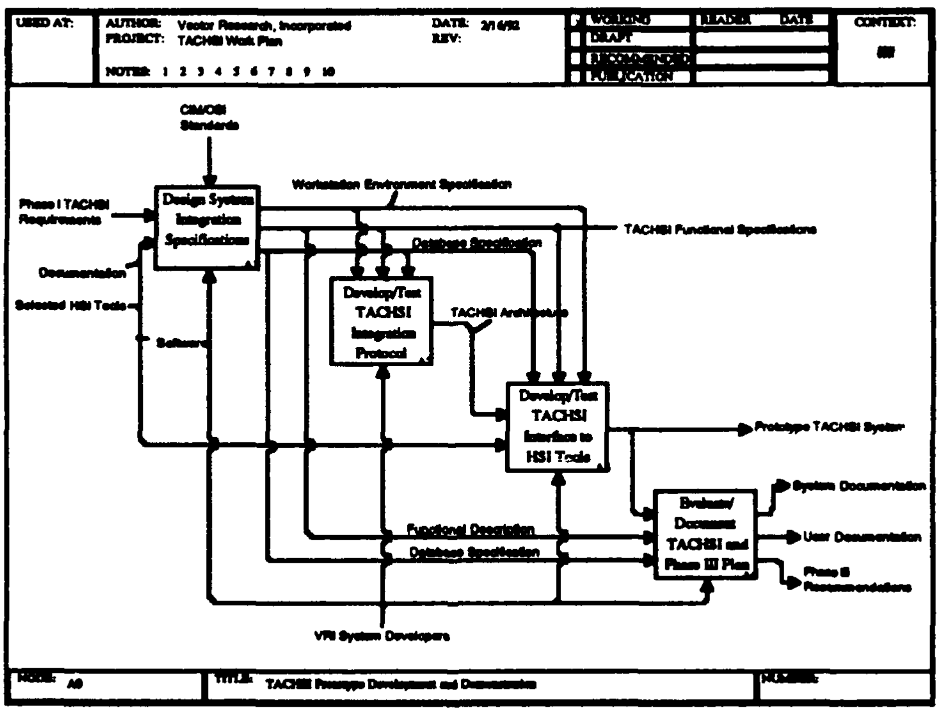


EXHIBIT 27: TACHSI SYSTEMS DEVELOPMENT APPROACH

During the Phase II TACHSI R&D effort, VRI will apply its software engineering expertise, and our library of software development tools to ensure the greatest functionality possible in the demonstration prototype. For example, VRI will use Computer Aided Software Engineering (CASE) tools, such as the $IDEF_{1X}$ feature within Design/IDEF, throughout the process to develop the data model and database specification document during Task 1. CASE tools will also be used to document subsystem specifications also in Task 1. These specification documents will be compiled and updated as necessary throughout Phase II to ensure consistency with the actual implementation.

VRI will apply structured analysis and design techniques early in the process to support modular construction, rapid development, and ease of migration in the future. In addition, VRI will use commercial off-the-shelf (COTS) products where advantageous to the development effort, and where the decision will not require the purchase of additional, expensive licensed products by the AF users.

Quality user and system documentation is critical to the life of a system, but the cost of producing this documentation cannot be ignored. The DoD STD 7935A **Military Standard for DoD Automated Information System (AIS) Documentation** contains guidelines for the minimum set of documentation needed for AIS of varying degrees of complexity. The proposed cost, level of effort, complexity and priority for TACHSI suggest only that an End User Manual is required. However, a Functional Description, which includes a Subsystem Specification, and a Database Specification, are invaluable to the success of the effort. The documents will be composed primarily of the output from CASE tools, i.e., data flow diagrams, entity relation diagrams, etc.

The central core of TACHSI is the integration architecture, which includes the interface to the user, the HSI models, and the databases.

The details of this integration will be outlined in the TACHSI Integration Protocol (TIP), documented in Task 1 and implemented in Task 2. The actual HSI and planning models, i.e., SAINT, $IDEF_0$, etc., are driven from the TIP implementation. TIP's design will reflect the necessary functions which supports ASD planners, while retaining modularity and flexibility to accommodate additional models in the future. The TIP description will identify the basic system building blocks, e.g., process, input, mechanism, output, constraint, performance function, etc., and define the interfaces needed to specify, store, and use them in conducting planning studies. The mapping from IDEF to SAINT for task networks of varying complexity will be accomplished in stages. The first stage will assume a deterministic task flow without branching; subsequent phases will address the impact of more complex task branching conditions, and will modify the building blocks and protocol accordingly.

After TIP is implemented in Task 2, selected individual HSI models will be incorporated into TACHSI in Task 3. $IDEF_0$, SAINT and the Performance database interface will be will be added first, followed by Isoperformance. Simple task networks will be implemented first, followed by increasingly complex networks. Implementation tradeoffs between increased network complexity versus expanded HSI analysis functionality will be made during Task 3, in concert with feedback from user groups and the AF sponsor. User feedback will play a critical role in this task, as interim demonstration prototypes of TACHSI will be made available for evaluation. Several trips are planned to ASD to solicit this feedback.

Task 4 will synthesize the results of the demonstrations and evaluations and prepare a roadmap for operational system development and potential commercialization in Phase III. The final report will be prepared, presented, and revised during Task 4.

Figure 28 contains a schedule for completing the four tasks in the Phase II approach. An 18-month project duration is proposed to include frequent trips to the sponsor. These include the standard kick-off and end-of-project meetings. Also included is a major technical interchange meeting to present the system and database specification documents after completion of Task 1, and to get AF review and approval prior to the start of the development efforts in Tasks 2 and 3. In addition, four trips are planned to ASD to solicit user feedback at various stages in the TACHSI prototype development effort. These are scheduled to occur at the end of Task 2, and at subphases within Task 3 as different HSI models and functionality are added. Major milestones are included in the schedule to correspond to delivery of interim and final reports.

Air Force support should include:

- machine readable and hard copy source code in FORTRAN for the C-SAINT simulation model;
- machine readable and hard copy source code in Pascal for the Isoperformance software package;
- access to CSERIAC data, as needed, to populate the performance database; and
- user feedback via technical interchange meetings and interim demonstrations regarding desirable features of the software, e.g., desired characteristics of the TACHSI user interface.

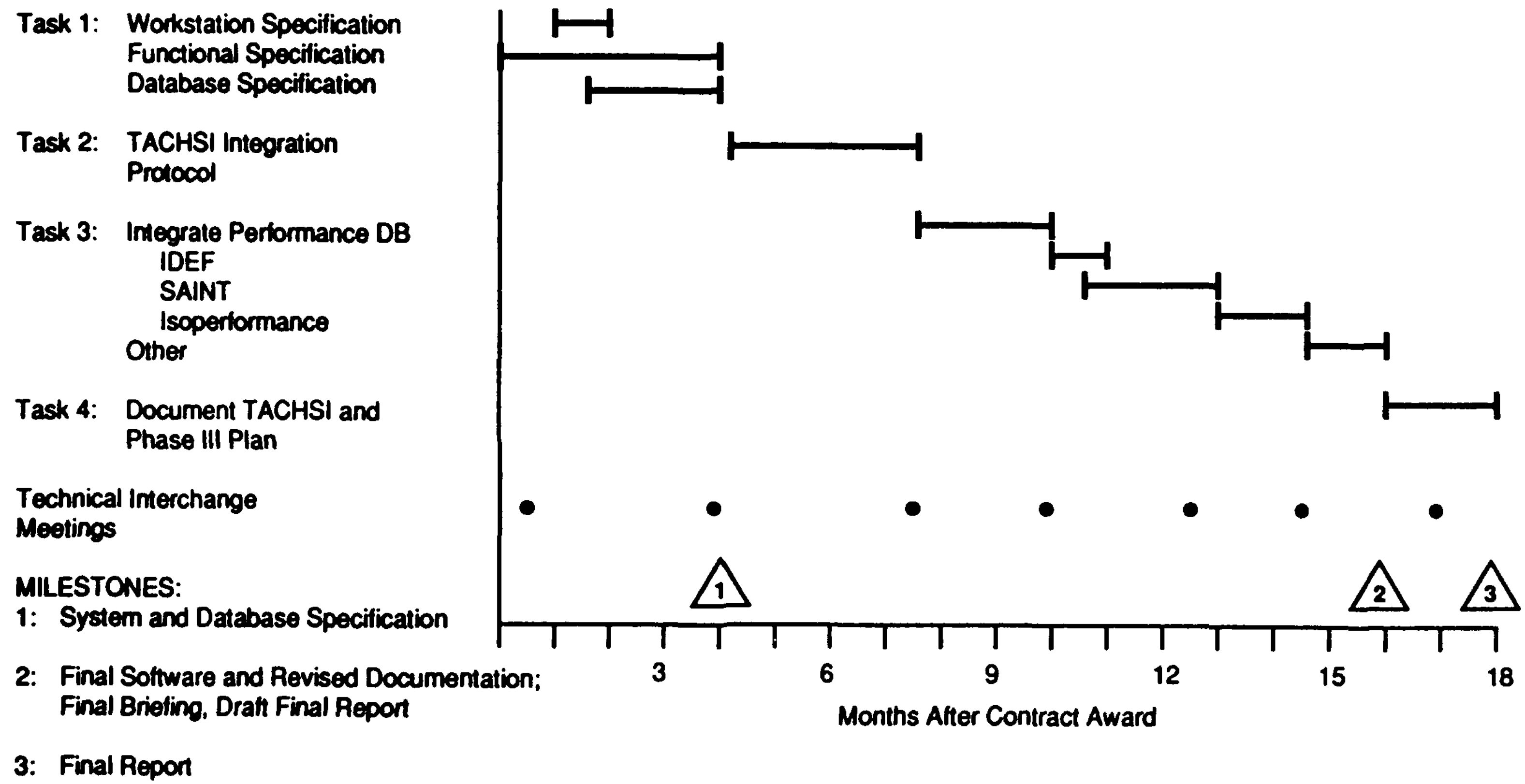


FIGURE 28: PHASE II SCHEDULE

5.2 TASK 1: DESIGN TACHSI SYSTEM INTEGRATION SPECIFICATIONS

The purpose of this task is to establish the functional, environment, and database specifications of TACHSI in sufficient detail to proceed with prototype system development. The results of Phase I, and available documentation on selected HSI tools, will provide the input to the process. The task will generate three specification documents which define the workstation environment for the prototype system, the functional and subsystem characteristics, and the databases. The documents serve as controls in subsequent tasks. The primary control within this task are DoD standards regarding Open Systems Integration and Corporate Information Management technical architectures.

The three subtasks within task 1 focus on producing each specification document. As indicated in figure 28, these subtasks will be conducted concurrently, with considerable interaction among the developers.

5.2.1 WORKSTATION ENVIRONMENT SPECIFICATION

Specifying the workstation environment is a nontrivial task, in that it may have considerable impact on the development effort and the ease in migrating toward the operational system in Phase III. As noted in the Phase I report, tool users prefer a platform with a graphical window and mouse interface, network access to shared databases, and device-independent applications. The move in DoD toward open system architectures over the next five years will make it easier to comply with these preferences. In the interim period covered in this Phase II effort, open systems are one of several considerations.

The two platforms being considered are the Macintosh II running Mac/OS or a SUN Sparc running UNIX. Both support a graphical user interface and a windows environment. The decision process will consider these and other factors:

- availability of software development toolkit and prototyping widgets;
- availability of platform in ASD for demonstration and user evaluation;
- compliance with the Government's Application Portability Profile for open system environments, as outlined in PB91-201004;
- cost of any proprietary packages (e.g., Design/IDEF, or SQL-compatible relational database management system) to the AF; and
- software code and COTS package portability from prototype to operational platform.

5.2.2 TACHSI FUNCTIONAL SPECIFICATIONS

The TACHSI functional specifications will start with this requirements document produced in Phase I and add sufficient detail to identify specific system functions, subsystems, and interactions among subsystems. Documentation for selected HSI tools, identified in section 3.2, will also be used.

The resulting document will form the basis for mutual understanding between the TACHSI developers and the AF users for TACHSI. It will reflect the definition of the system requirements and provide the ultimate users with a clear statement of the operational capbility to be developed. Its form and content will conform to DoD Std 7935 A.

The document will also contain a system/subsystem specification to guide the development in Task 2. This will logically break the system into separate areas of responsibility or functions, where each breakdown is composed of a software unit or series of units. The primary TACHSI functions which will be described in the system specification include:

(1) Describe the system;

(2) Populate performance database;

(3) Construct system simulation scenario;

(4) Exercise the models; and

(5) Evaluate the results.

The document will also define the functions and subsystems for the TACHSI Integration Protocol (TIP). In addition, crosswalks among model components, such as the matrix in figure 29 which defines the interaction and component mapping between IDEF and SAINT constructs, will be prepared and included.

5.2.3 DATABASE SPECIFICATION

The database specification will be prepared to document the TACHSI entities and table formats needed to support the functions, models, and interfaces of the system. Entity-relation diagrams will be created using a CASE tool, such as Design/$IDEF_{1X}$. Specifications will be sufficiently detailed to permit software coding and database generation by the development group in Task 2. Test data sets will be identified for use throughout system development.

Database design implications of applicable data standards as they apply to product, mechanical design and logistics data (i.e., PDES (Product Data Exchange Standards), IGES (Initial Graphics Exchange Specification), STEP (ISO Standard for the Exchange of Product Model Data), and CALS will be considered here. Direct interfaces versus translation routines will be evaluated.

While the use of product data exchange standards will ensure compliance with CALS requirements as MilStd 1840A is applied to new DoD procurement contracts, the implementation within the prototype system is viewed as less critical than for the operational system. This will also

IDEF	SAINT: LABL	Time	Predecessor	Resource	Priority	INCM	DMOD	UTCH	SWIT	MODF	BRANCHING	STATE VAR.	MONITOR	CLEARING	NETWORK
Input			F			S, F	S				S		S		
Function	F	F						E		F		S		F	
Control					F	S,F	F		F		F				G, S
Mechanism		R		R				E		R, E	R			R, E	
Output											G, S, R, F			F	
Network		S							S	S, R, E	G, S, R, F	S	S, F	S, R	G, S

Legend for Information Categories

Environmental Factors
Function or Task Characteristics
Global System Characteristics
Resource Attributes
Scenario Specific State Conditions

FIGURE 29: MAPPING BETWEEN SAINT AND IDEF COMPONENTS

permit cost-effective communication of product data (e.g., system geometries, subassembly locations and characteristics) among government and industry/contractor personnel. In the future, access to graphical data will facilitate analysis by operator graphic and CAD models, and ensure that analyses are performed on the most current, consistent, and accurate product description data.

The specifications will be presented to the AF at a technical interchange meeting at the completion of Task 1. Subsequent development will not start until the sponsor agrees to the specifications outlined in these documents.

5.3 TASK 2: DEVELOP/TEST TACHSI INTEGRATION PROTOCOL (TIP)

The purpose of this task is to develop and test the integration architecture for TACHSI. The specification documents from Task 1 will serve as controls during this task. The output will be a demonstrable interface capable of showing user interface screens, function selections, and sample output capabilities. Structured design, rapid prototyping and software engineering toolkits will be used during the software development process. Test data, defined during Task 1, will be used to test, evaluate and demonstrate the product. The TACHSI framework and the TIP components are shown in figure 30, with the TIP components shaded.

User interface screens will be prototyped and linked to test datasets for demonstrations. Special interface screens will be constructed to populate the performance database, and to formulate design scenarios and identify design constraints for system analysis. Output formats will be defined for a set of representative ASD HSI tasks.

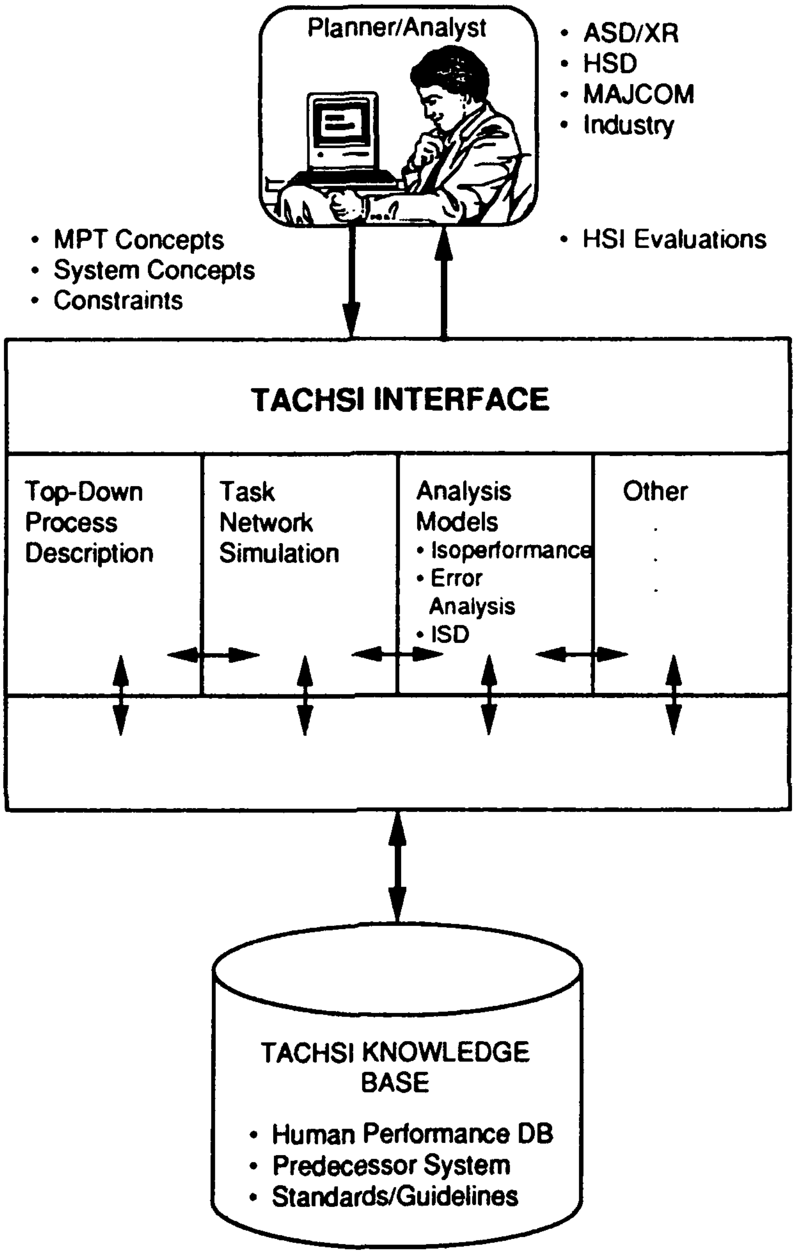


FIGURE 30: TACHSI FRAMEWORK WITH TACHSI INTEGRATION PROTOCOL COMPONENTS SHADED

Integrating existing tools under a common architecture is preferred to developing a completely new approach. Properly designed, the TIP architecture will efficiently bridge interconnections among models and methods. The use of existing tools such as IDEF and SAINT within the integrated architecture increases the operational feasibility, since the tools have some credibility established. The structure permits flexibility in adding new tools to the architecture. As the tool kit expands, the user will be able to analyze a wider range of issues, (e.g., concept issues such as mission effectiveness), and a larger class of users, beyond just the MPT community, may benefit. An intelligent interface among the tools also reduces the user's training burden.

Specifying HSI system and task data is the primary driver in preparing for many analyses in TACHSI. The desired level of task decomposition, the source of data (i.e., access to predecessor system), or the presence of expert system aids will significantly alter the time needed to describe the nature of HSI under study. Consistency across descriptions is necessary to ensure TACHSI's effective use across analysis models. Simplifying assumptions may be necessary in the prototype implementation, and full decomposition and aiding capability may be deferred until operational system development in Phase III. Similarly, the degree of task network sophistication accommodated in the prototype may be reduced to demonstrate the concept, and full branching capabilities may be deferred as well.

TACHSI will include capabilities to prepare both standard and ad hoc analysis reports. Task 2 will focus on the standard reports; the ad hoc reports will be deferred. The library of standard reports will evolve as tools are added and user requests expand. Contents of standard reports should include design/analysis graphs supporting system and MPT tradeoff studies, high driver identification, and cost assessment.

SAINT simulation output will be stored in databases for subsequent analysis, such as the examples presented in section 3.4.

Reporting and charting features represent the primary communication device among system developers throughout the acquisition process. The TIP will support this process through representative charts and graphs.

A prototype of the architecture will be demonstrated to ASD users at the completion of Task 2. Comments and feedback, especially regarding system functions and user-oriented interfaces, will be critical to ensuring the success of the prototype system.

5.4 TASK 3: DEVELOP AND TEST TACHSI INTERFACE TO HSI TOOLS

Whereas Task 2 establishes the framework for the overall system, Task 3 takes the framework and makes it useful by integrating the selected HSI performance models in a phased approach. The basic subtasks applied within each phase are:

(1) Develop a demonstration prototype to demonstrate functionality and interfaces for each phase;

(2) Test and evaluate with users; and

(3) Integrate operating tools within TACHSI, and update interfaces and documentation as necessary.

The product of Task 2 is the final prototype TACHSI system, complete with interfaces to functional planning tools. The specification documents produced in Task 1 are again used as controls to the process. Inputs include the TACHSI architecture and the software for the suite of HSI tools.

As mentioned previously, the HSI tool suite will include the $IDEF_0$ methodology for top-down process decomposition, the SAINT task network simulation model, the IDEAL performance database, and an implementation of the Isoperformance method for trading off training, personnel and equipment. Task 3 will integrate these tools in the following sequence or phases:

Phase	Tool interface and condition (if any)
1	Performance database for selected simulation conditions with limited branching.
2	$IDEF_0$.
3	SAINT simulation and output analysis/reporting.
4	Isoperformance analysis.
5	Expansion to performance database and simulation interface for more complex activity branching conditions.

At the conclusion of each phase, the prototype system will be demonstrated and delivered to users at ASD for their use, comments, and feedback. The specific functions to be developed and tested in phase 5 will depend on the results of the prior phases. An alternative implementation in phase 5 could involve other types of HSI analysis or reporting capability. For example, this could include: an assessment of operator workload based on the SAINT simulation results showing resource utilization over time error analysis for safety assessment; a refined linkage to ISD models such as the ISD/LSAR Decision support system; or an identification of training high drivers.

5.5 EVALUATE AND DOCUMENT TACHSI AND PHASE III PLAN

The primary products of this task include a current system specification manual and end user documentation, as well as a final report which includes recommendations for Phase III. The system specification document, which includes the functional and database specifications, will be updated to reflect the results of the iterative process of design and development followed throughout Tasks 2 and 3.

User documentation will be developed and will include the following:

- System summary, including system environment, modes of operation;
- System access, including first-time use, and scenarios of use in design; and
- Processing reference guide, including error recovery and messages.

A final user and sponsor review of the prototype system will be conducted at the conclusion of the Phase II effort.

The Phase III recommendations will present directions for the operational system development, and will highlight those areas missing from the prototype system. Included in this latter group are

- Design audit trail and version control;
- Multi-user, network operations;
- Interfaces to product design/CAD/CAE systems, and operator graphic representations; and
- Issues for software migration to the operational system.

The final report and Phase III recommendations will also outline a plan for commercialization.

5.6 RESOURCES

Estimated Phase II project personnel staffing resources include four people with a mix of skills. These include:

- Project Leader/Principal Investigator (part time);
- Junior Human Factors Engineer (part time);
- Database analyst (part time); and
- Software engineer (full time).

Overall project duration for implementing the prototype system is 18 months.

5.7 CONCLUSION

This Requirements Analysis Document leads the way for developing a planning tool for analyzing human system integration designs in the concept phase of system acquisition. The automated TACHSI tool will be a portable desktop decision aid. It has potential application by elements in Air Force program offices and organizations, and complements efforts in the private sector by those who are involved with the conceptual design of complex human-operated systems.

REFERENCES

Allan, K.E., and Johnson, J.R.. (March 1991). *Development of an IMPACTS Analysis Architecture for Concept Exploration*, San Antonio, TX: UES, Inc.

Bachert, R., Evers, K., Hoyland, C., and Rolek, E. (1982). "Static and Dynamic Model Integration for a SAM C^3 Simulation via $IDEF_0$/SAINT." *Proceedings of the 1982 IEEE International Conference on Cybernetics and Society*.

Bachert, R., Evers, K., Hoyland, C., and Rolek, E. (1983). "$IDEF_0$/SAINT SAM Simulation: Hardware Human Submodels," *Proceedings of the IEEE 1983 National Aeropsace and Electronics Conference (NAECON).*

Bergquist, T. and Gould, B. (1991). "Building a Weapon System Optimization Model," *IMPACTS Bulletin*, III(1), January/February

Boff, K. and Lincoln J. (1988). *Engineering data compendium: Human Perception and Performance* (Volumes 1-3). Wright-Patterson AFB, OH: Armstrong Aerospace Medical Research Laboratory.

Booher, H. (editor). (1990). *MANPRINT, An Approach to Systems Integration*, New York: Van Nostrand Reinhold.

Booher, H. and Hewitt, G. (1990). "MANPRINT Tools and Techniques," in *MANPRINT, An Approach to Systems Integration* (edited by H. Booher), New York: Van Nostrand Reinhold, pp 343-390.

Chubb, G. P. and Hoyland, C.M. (1989). "Systematic Modeling of Multi-operator Systems to Evaluate Design Concepts," *Applications of Human Performance Models to System Design*, edited by G. McMillan et al., New York: Plenum Press.

Department of the Air Force, (1987, 15 July). *Training Handbook for Designers of Instructional Systems* (AFP 50-58), Volumes 1-6, Washington, DC.

Department of the Air Force, (1991). *Joint Mission Need Statement for Human Systems Integration Analysis System with Integrated Database and Job Aids (Draft)*, Washington, DC: AF Directorate of Manpower and Organization (AF/MOR).

Department of Defense. (1991a). Defense Acquisition Directive (DoDD 5000.1). Washington, DC: Office of the Secretary of Defense.

Department of Defense. (1991b). Defense Acquisition Management Policies and Procedures (DoDI 5000.2). Washington, DC: Office of the Secretary of Defense.

Department of Defense. (1991c). Defense Acquisition Management Documentation and Reports Manual (DoD 5000.2-M). Washington, DC: Office of the Secretary of Defense.

Dynamics Research Corporation. (April 1991). *Joint Service Instructional Systems Development Logistic Support Analysis Record Decision Support System (ISD/LSAR DSS) Version 4.1 System Overview*. Andover, MA: Dynamics Research Corporation.

Evers, K.H., and Bachert, R.F., (1987). "The IDEAL Modeling Methodology: Capabilities and Applications," *First Annual Workshop on Space Operations Automations and Robotics (SOAR'87)*, pp 153-158.

Evers, K.H., Bachert, R.F., and Santucci, P.R. (1981). "SADT/SAINT Large Scale analysis simulation methodology," *Proceedings of 1981 Winter Simulation Conference.*

Fleger, S.A., Permenter, K.E., and Malone, T.B. (1987). *Advanced Human Factors Engineering Tool Technologies*, Fairfax, VA: Carlow Associates, Inc.

Flint, R.L., and Johnson, K.M. (March 1991). *Integrated Manpower, Personnel and Comprehensive Training and Safety (IMPACTS) Process Handbook*. Washington, DC: Hay Systems, Inc. for IMPACTS Policy Office, HQ USAF/MOR.

Gorman, Maj, M.C. (1991 Nov/Dec). "Human Factors in Concurrent Engineering", *IMPACTS Bulletin*, III(4), pp 1-4.

Graine., G. (1988). "The Engineering Syndrome vs. the Manpower, Personnel, and Training Dilemma," *Naval Engineers Journal*, pp 51-59.

Haines, L.A., and Evers, K. (1990). "An $IDEF_0$ Representation of the Instructional System Development (ISD) Process - Why it works." *Proceedings of the IEEE 1990 National Aerospace and Electronics Conference (NAECON).*

Kennedy, R.S., Jones, M.B., and Turnage, J.J. (October 1-4, 1990). "A Meta-Model for Systems Development Through Life Cycle Phases: Coupling the Isoperformance Methodology with Utility Analysis," paper presented at the SAE AEROTECH '90 Meeting, Long Beach, CA.

Kennedy, R.S., Jones, M.B., and Baltzley, D.R. (1989). *Regions of Isoperformance: An interactive Software Package for Trading off Training, Personnel, and Equipment*, (AMRL-TR-89-003), Wright-Patterson AFB, OH: Harry G. Armstrong Aerospace Medical Research Laboratory, HSD, AFSC.

Kerchner, R. (1991 June). *Integrated Manpower, Personnel, and Training (MPT) Analysis System, Part I Front End Analysis*, Reston, VA : Hay Systems, Inc. and PRC, Inc.

Meta Software. (1991). *Design/IDEF User's Manual for the Apple Macintosh*, Cambridge, MA: Meta Software.

Miller, T., and Boyle, E. (1991, January). *Top-Down System Tool for Logistics*, (AFHRL-TP-91-3), Brooks AFB, OH: AF Human Resources Laboratory.

Perceptronics, Inc. (1991). "PERCNET: A Graphical Modeling and Knowledge-Based Simulation Environment for Human System Integration," (product literature), Woodland Hills, CA: Perceptronics, Inc.

Potempa, K., and Gentner, F. (1989). *Manpower, Personnel, Training and Safety in the Air Force Weapon System Acquisition Process*, Brooks AFB, TX: Human Systems Division.

Rossmeissel, P., Akman, A., Kerchner, R., Faucheux, G., Wright, E., and Sheilds, J. (1990). *Analysis of Manpower, Personnel, Training and Safety in the Acquisition of Air Force Systems: Requirements and Capabilities*. Washington, DC: Hay Systems, Inc.

Rue, R.C., Black, M., Rose, D., and Bartenwerfer, D. (1991). *Air Force Conceptual Weapon System Optimization Model*, San Antonio, TX: Systems Research and Applications Corporation.

Seifert, D.J., and Chubb, G.P. (1978). *SAINT: A combined simulation language for modeling large complex systems*, (AMRL-TR-78-48), Wright-Patterson AFB, OH: Aerospace Medical Research Laboratory, AMD, AFSC.

Shields, J., Rossmeissl, P., and Johnson, D. (1989). "Manpower, Personnel, Training and Safety in the Air Force Weapons Systems Acquisition Process," Dayton, OH: National Aerospace and Electronics Conference.

Shields, J., Johnson, K. and Fiviello, R. (1990). "The Acquisition Decision Process (Chapter 10)," in *MANPRINT, An Approach to Systems Integration* (edited by H. Booher), New York: Van Nostrand Reinhold, pp 301-319.

Smith, B.R. (1991, June). "Six Years into the A^{3}I Program: Progress and Problems", *Human-Centered Technology for Maintainability: Workshop Proceedings* (AL-TP-1991-0010), (edited by E. Boyle et al.), Wright-Patterson Air Force Base, OH: Human Resources Directorate, Logistics Research Division.

Smith, B.R., and Banda, C.P. (1990, November). "Use of a Knowledge-Based System to Assess Aircrew Training Requirements as Part of Conceptual Design", *Proceedings of the 1989 IEEE International Conference on Systems, Man, and Cybernetics*, Cambridge, MA.

SofTech, Inc. (1981, June). *ICAM Architecture, Part II*, AFWAL-TR-81-4023, Volume I - Volume IV, Wright-Patterson Air Force Base, OH: Air Force Wright Aeronautical Laboratories.

SofTech, Inc. (1986). "Sample Application of IDEAL", Fairborn, OH: SofTech, Inc.

U.S. General Accounting Office (GAO), (1985, September 27). *The Army can better integrate manpower, personnel, and training into the weapon systems acquisition process* (Report GAO/NSIAD-85-154).

Wortman, D.B., Duket, S.D., Seifert, D.J., Hann, R.L., and Chubb, G.P. (1978). *The SAINT user's Manual*, Wright-Patterson AFB, OH: Aerospace Medical Research Laboratory, AMD, AFSC.

U.S. GOVERNMENT PRINTING OFFICE 750-113